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INVESTIGATION OF PITOT AND STATIC SYSTEM LEAK EFFECTS

December 1976

Final Report

AFFTC

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of an investigation of the effects of leaks into pitot-static systems. Flight test data was obtained on a KC-135A. Ground tests on the aircraft pitot-static systems and laboratory tests produced the data needed to interpret the flight test results and to show the effects of parameters not investigated in flight. The program was initiated as a result of the AIMS related tests to identify and correct sources of altimetry

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system errors. The tests identified the primary parameters affecting leak-induced altimeter errors as leak hole size and pressure differential across the hole for a specific system geometry. Secondary effects were leak location, airspeed, and to a limited extent, altitude. The static system volume significantly affected the rate of change of indicated altimeter values during ground leak checks. Airspeed indicator errors due to pitot system leaks were primarily dependent on airspeed, cabin pressure, and leak hole size. Pitot system volume would affect the magnitude of indicated leak rate during a leak check. Data analysis required use of leak check methods different from those usually applied to pitot-static systems. It was found that a static pressure system leak check criteria based solely on permissible altitude error might allow leaks which were unacceptably large when system integrity was considered. The continued use of current Air Force pitot-static system leak check criteria should result in negligible airspeed and altitude errors.

SUMMARY

The DOD AIMS program investigated the magnitude of altimeter errors due to pressure fields and equipment. The error due to static system leaks was recognized as an unknown quantity. A test program on a T-38 identified the altimeter errors at several flight conditions for known leak rates. The test program on the AFFTC NKC-135A was established to investigate the effects of leaks in the pitot-static system of a large aircraft and to determine what variables, including system volume, affected the magnitude of leak-induced altimeter and airspeed errors. Major emphasis was placed on altimeter error information.

Laboratory tests were conducted to establish calibrations for the leak valves used on the test flights and to attempt to create a generalized model which could be applied to analysis of flight test data and used to predict the errors in a different aircraft static system. Static system volume was found to be one of the principal parameters affecting the results of a leak test on a static system, i.e., a small volume system caused a more rapid altimeter response to a ground test leak than did a large volume system. A method to determine system volume was confirmed by laboratory tests and the effect of volume on leak rate through the calibrated leak valves was ascertained. The volumes of the test pitot-static systems on the test aircraft were measured and found to be less than those on a typical fighter-class aircraft.

Pressure differential across a leak valve was found to be a key parameter in both laboratory and flight test data. In order to correlate ground test data and develop a generalized presentation of leak effects on KC-135A aircraft, ground test leak rate data was analyzed at one particular leak valve pressure differential. New leak check procedures based on a constant pressure differential were developed for utilization of KC-135A leak effects presented in this study.

Pneumatic-mechanical instruments were not sensitive enough to produce data which delineated the trends and relative effects of the various parameters affecting the leak-induced errors. Use of electrical digital output altimeters produced data with less scatter.

Altimeter errors were found to depend primarily on leak hole size and cabin pressure differential and secondarily on altitude, airspeed, and leak location relative to the altimeter. An increase in the primary parameters caused an increase in the altimeter error (indicated altitude less than actual flight altitude). The leak closest to the altimeter caused the greatest error. Increasing airspeed caused slightly greater altimeter errors. The computed pressure error sensed by the altimeter increased slightly with increasing flight altitude. Thus, the altimeter error for a leak at a high altitude would be greater than predicted by use of the standard atmosphere equations applied to pressure error data acquired at a lower flight altitude. Leak-induced airspeed errors were found to depend on leak hole size, airspeed, and cabin pressure differential. Static system leaks caused lower airspeed readings and pitot system leaks caused higher readings at the airspeeds flown during the tests. Pitot-leak induced airspeed errors increased with increasing leak hole size and cabin pressure differential and decreased with increasing airspeed.

Leak check rate of descent was found to increase with increasing

hole size, increasing pressure differential, and decreasing system volume. For the same indicated leak rate, a large volume system could be expected to have a greater altitude error because the leak hole and stabilized leak flow rate would be larger. System configuration can affect the altimeter error by the extent that the stabilized leak flow is restricted beyond the leak hole.

It appears that current Air Force leak rate criteria result in negligible altitude errors. Leak rates must reach several thousand feet per minute before their effect is noticeable. The relationship between the maximum allowable leak-induced altitude error for an aircraft and the AIMS criteria will depend on the altitude error curve resulting from all other causes.

PREFACE

The test program was initiated at the request of the AIMS System Program Office (SPO) and was initially authorized by AFFTC Project Directive 74-3, 6 July 1973. Before the test was completed, the AIMS flight test program was terminated and the AIMS SPO was deactivated. The test was then completed as an AFFTC in-house project under AFFTC Project Directive 74-3A, 16 May 1974.

The author wishes to acknowledge the contributions of several people associated with this project. Lt Col Michael V. Love was the program manager. Captains Paul J. Mathieu and Gary W. Clark were assigned consecutively as project engineers. Mr. Willie L. Allen and Mr. Albert G. DeAnda assisted the engineering effort during parts of the planning, testing, and data analysis phases of the program.

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INTRODUCTION

BACKGROUND

A 1966 study (reference 1) determined that the maximum acceptable error in aircraft altimetry systems should be ±250 feet for flight in positively controlled airspace with 1000 feet vertical separation between flight levels. The Department of Defense AIMS program involved a considerable effort to determine and reduce errors caused by pressure fields, static sources, computers, and altimeters. During the flight testing for the AIMS program, it became apparent that there was only limited knowledge about the errors resulting when leaks existed in pitot-static systems.

The investigation reported in a 1971 AFFTC Technical Information Memorandum (reference 2) was conducted to determine the relationship between leak rates and the corresponding altimeter error for several in-flight conditions. The tests were conducted on a T-38 aircraft using the standard 4.8 pounds per square inch (psi) (9.77 inches of mercury (in. Hg)) cabin pressure differential and various size leak holes. It was apparent from the test results that a further effort should be made to completely define the functional relationships affecting leak-induced pitot-static system errors.

These follow-on tests were conducted as a result of the recommendation to conduct further testing in a cargo aircraft with a large pitot-static system volume. The AFFTC possessed NKC-135A aircraft was considered ideal for the test because of its large airspeed and altitude envelope and capability to change the cabin differential pressure in an analog manner from 0 to 8.6 psi (17.51 in. Hg).

The test flights were conducted in two phases using NKC-135A aircraft S/N 55-3135. In the first phase, eight data collection flights were conducted using C-19 altimeters as part of the test instrumentation. Subsequently, a set of Hamilton Standard digital altimeters was installed on the aircraft. Using the digital altimeters, five data collection flights were accomplished totalling approximately nine hours. The results of this report are based on the data collected during the second series of flights.

OBJECTIVES

The overall program objective was to determine the magnitude of leak-induced altitude and airspeed errors, using a KC-135A, to aid in establishing pitot-static system leak rate criteria for AIMS equipped aircraft. Current Air Force leak rate criteria are not related to nor are they based on the resultant in-flight altitude errors. The detailed objectives were:

1. To determine static system leak-induced altitude and airspeed errors for various airspeeds, altitudes and cabin differential pressures.

2. To determine pitot system leak-induced airspeed errors for various airspeeds, altitudes, and cabin differential pressures.

3. To investigate the effects of static system volume and leak location on leak-induced altitude and airspeed errors. It was recognized that system configuration would affect results.

INSTRUMENTATION

The test instrumentation used on the final five flights consisted of two calibrated Hamilton Standard HSA 101 Digital Encoding altimeters, two calibrated C-19 altimeters, four calibrated F-1 airspeed indicators, three leak control valves, three calibrated leak valves, associated tubing, and a valve to provide additional static system volume consisting of 100 feet of 3/8 inch inner diameter hose (figure 1). A calibrated airspeed indicator and AAU-19 altimeter were installed in each of the pilot's, copilot's, and navigator's instrument panels. In addition, an auxiliary panel was mounted on the table at the navigator's station (figure 1). This panel contained the Hamilton Standard altimeters and a calibrated F-1 airspeed indicator in addition to the seven valves used in the testing. These instruments were designated altimeters No. 1 and No. 2 and airspeed indicator No. 3. The leak control systems associated with these indicators were numbered in a like manner so that the No. 1 leak control system was associated with altimeter No. 1, etc. The altimeter and airspeed indicators in the pilot's panel were each designated as No. 4. The remaining instruments were not assigned numbers since that was not necessary to simplify data acquisition or reduction.

The pitot and static lines of the test installation were each connected to the standard pilot's pitot and static system shown in figure 2. The test pitot line, about 17 feet long, was connected to the pilot's system several feet from the CPU-66 air data computer. The line to the pilot's instruments branched off the line nearer the pitot head. The nine feet long test static line was attached to the pilot's static line between the instruments and the static ports about ten feet from the point at which the line branched to the two static ports.

Each leak control system consisted of an ON-OFF valve in series with an indexed valve which had been calibrated to provide known leak rates. The indexed valves were vented to the cabin through the ON-OFF valves. This permitted accurate setting of the indexed valves prior to inducing a leak, and provided redundancy to insure a no-leak system for flight operations unrelated to this test. Twelve marks were placed 30 degrees apart on each of the valve shafts. The marks were numbered 0 through 11. Valve settings were recorded in terms of the number of full and fractional turns open, e.g., 1-6 was 1 + 6/12 turns open and 2-0 was 2 full turns open.

The two altimeter leak test units were connected by the ON-OFF volume valve. This allowed testing with an enlarged system volume, and it also allowed investigation of the effects of leak location and line length.

An additional calibrated C-19 altimeter was mounted at the navigator's panel and vented to the cabin. Cabin differential pressure was maintained by setting the cabin pressure to the desired altitude using this altimeter.

Several different ground tests were conducted to calibrate the leak valves and to develop information necessary to evaluate flight test data. Pressure data were measured by electrical pressure transducers. The instruments used were Kollsman Instrument Corporation Model KM60-C1 Precision Pressure Monitors. During tests related to pitot leaks, the volume flow rate of air was measured by a Fischer and Porter Flowrator Meter.

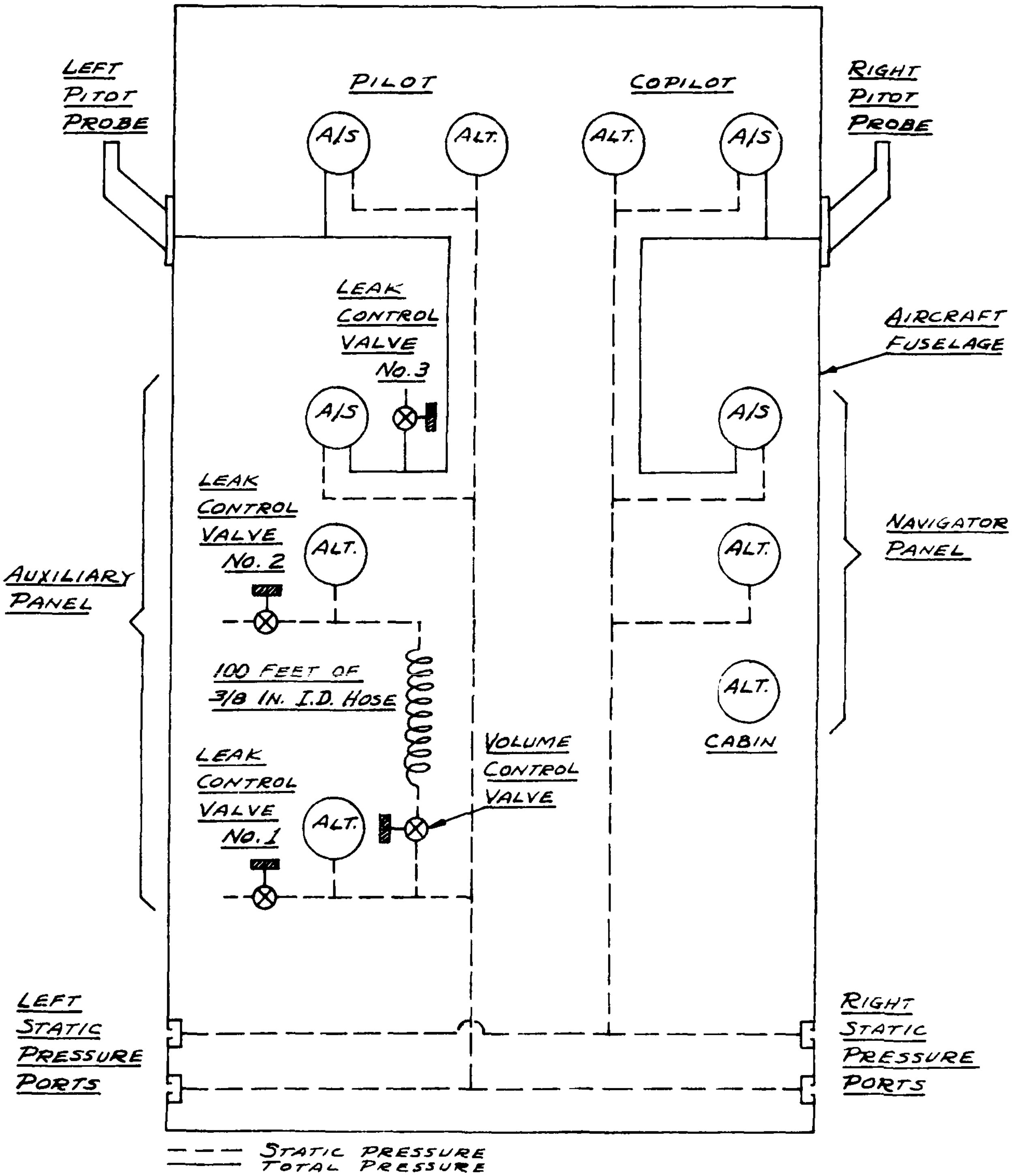
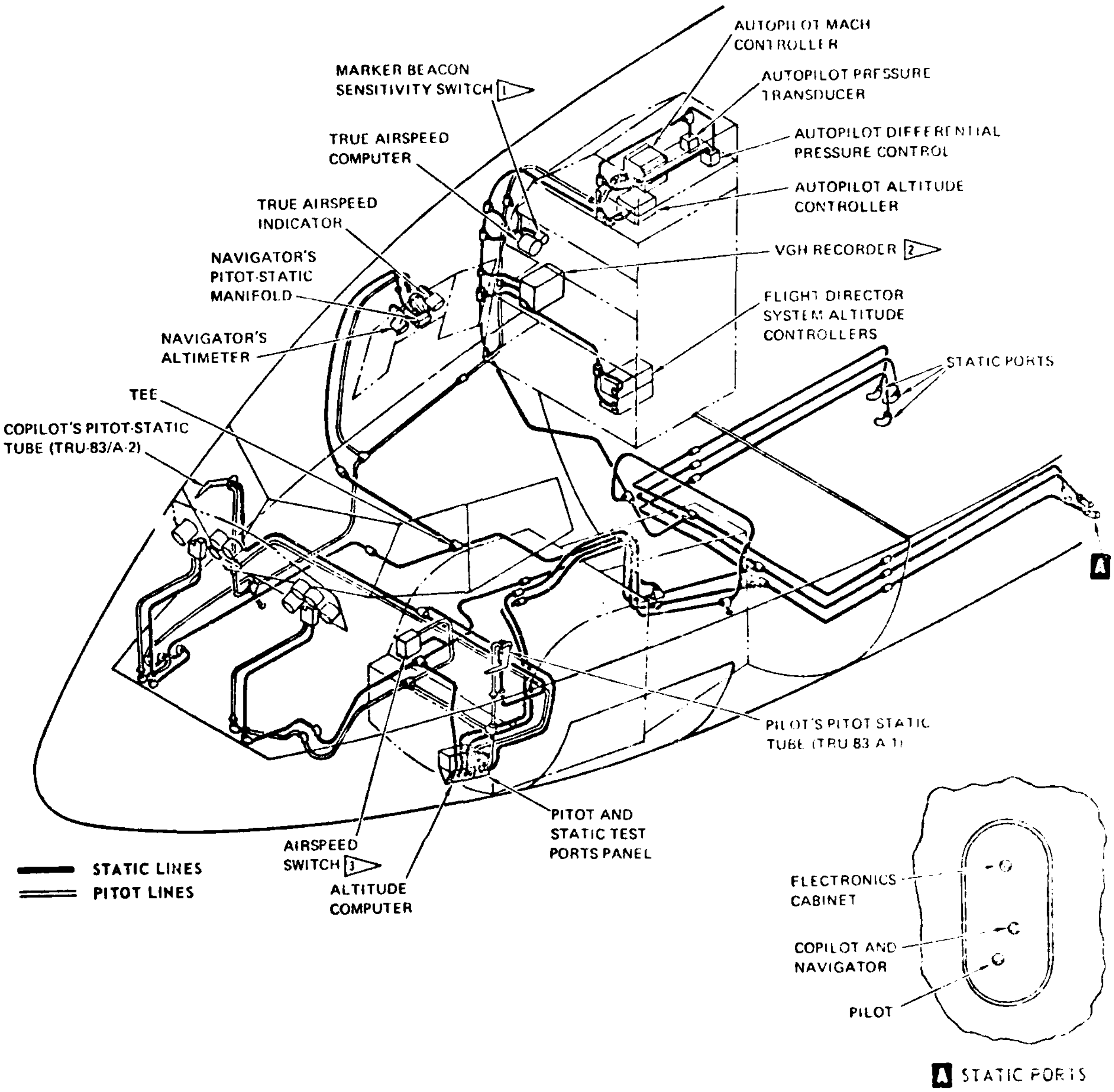


FIGURE 1 SCHEMATIC OF TEST INSTRUMENTATION ON TEST AIRCRAFT



1 AIRPLANES AF55 3118 THRU 3146

2 KC-135A AIRPLANES WITH SERIAL NUMBERS ENDING IN "0" OR "5"

3 EC 135C AIRPLANES

Source: Reference 4

FIGURE 2 DIAGRAM OF PITOT-STATIC SYSTEM ON TEST AIRCRAFT

TEST METHODS AND CONDITIONS

GROUND TESTS

Ground testing pertaining to this program consisted of two parts; tests in the laboratory and tests performed on the aircraft. The test instrumentation was designed to measure the in-flight parameters considered to be of primary importance. Prior to the flight tests, it was postulated that for a given static system an altimeter error due to a leak would be primarily a function of leak hole size, leak location, and pressure differential across the hole (essentially cabin differential pressure if the entire static system is contained in the pressurized portion of the aircraft). Additionally, it was considered desirable to be able to present the results of the investigation in a format which could be used directly in a ground check to determine what in-flight effect a given leak would have. The most direct format is in-flight altimeter error as a function of the static system leak check rate of descent. It was further postulated that the pressure change in a static system due to a leak would be a function of the leak hole size, pressure differential across the hole, and the system volume. Thus, it was necessary to know the volume of the pitot-static systems on the test aircraft and to know, via calibrations, the effect of specified valve settings for each leak valve.

Laboratory Tests:

To determine the effects of volume on the pressure change (rate of descent) due to a leak, several different tank volumes (131, 169, 205 in.^{3}) were fabricated and tested. The internal volumes of these test tanks were determined by filling each with water several times and measuring the water volume in a beaker graduated in milliliters.

Leak hole sizes (of unknown but presumably repeatable dimensions) were represented by specific settings on the indexed leak valves. Data concerning the effects of hole sizes (leak valve settings) and volume were collected by experiments utilizing the apparatus depicted in figure 3. The procedure was to measure the atmospheric pressure using the Kollsman Precision Pressure Monitor. Then the test volume was evacuated to a predetermined pressure and the valve on the pump line was turned off. With the leak valve at a particular setting, the ON-OFF valve was turned on. Pressure readings (in the form of counts) were recorded at five-second intervals by using the display hold feature of the pressure monitor. This procedure was repeated five to seven times depending on the proper choice of the initial pressure and the timing accuracy of data measurements. Each pressure reading was converted to pressure altitude by using the Kollsman supplied calibration tables. The data for one such series of tests is shown in figure 4.

Curves faired through the data are nonlinear. Thus, the slope (rate of descent) at any point on a curve is a function of the pressure altitude (also pressure differential across the valve). To consistently interpret data obtained on different days, the rate of descent effect of each valve setting and volume was determined at a constant pressure differential across the valve. The value chosen was ΔP = 9.344 in. Hg. This number represents sea level pressure minus the pressure at 10,000 feet in the standard atmosphere.

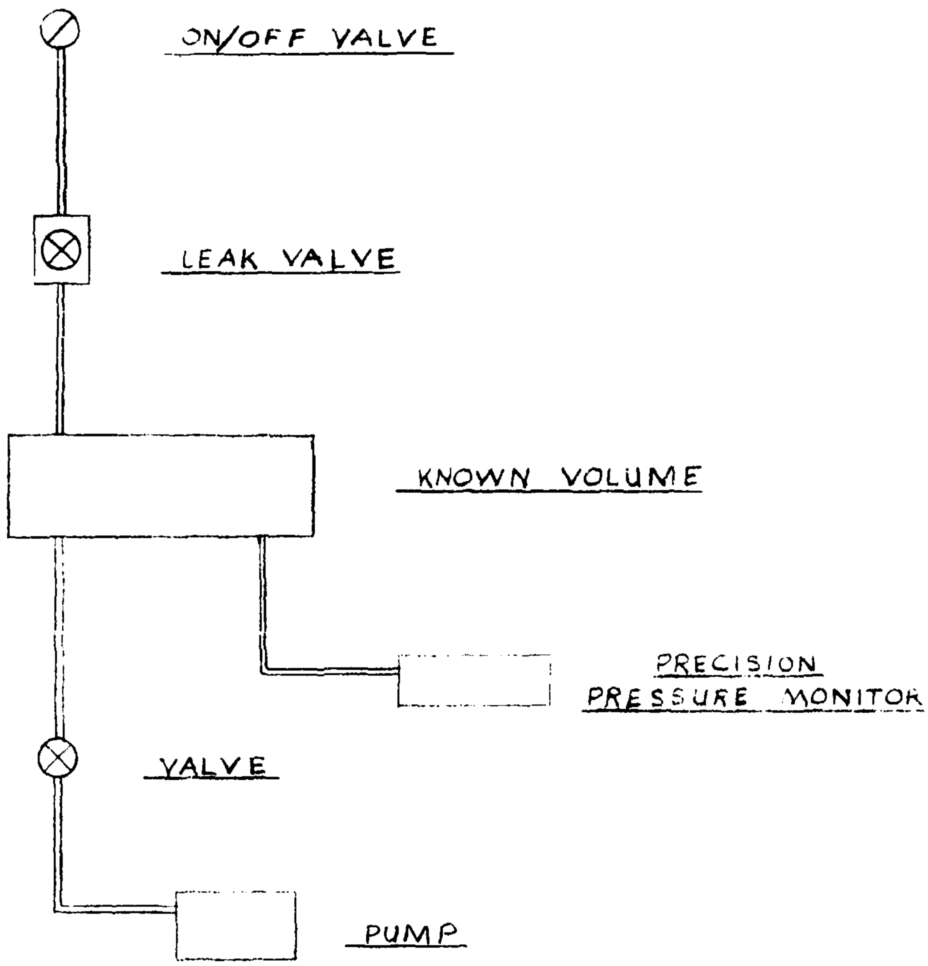


FIGURE 3 SCHEMATIC OF APPARATUS USED TO CALIBRATE LEAK VALVES AND DETERMINE VOLUME EFFECTS ON GROUND LEAK RATES

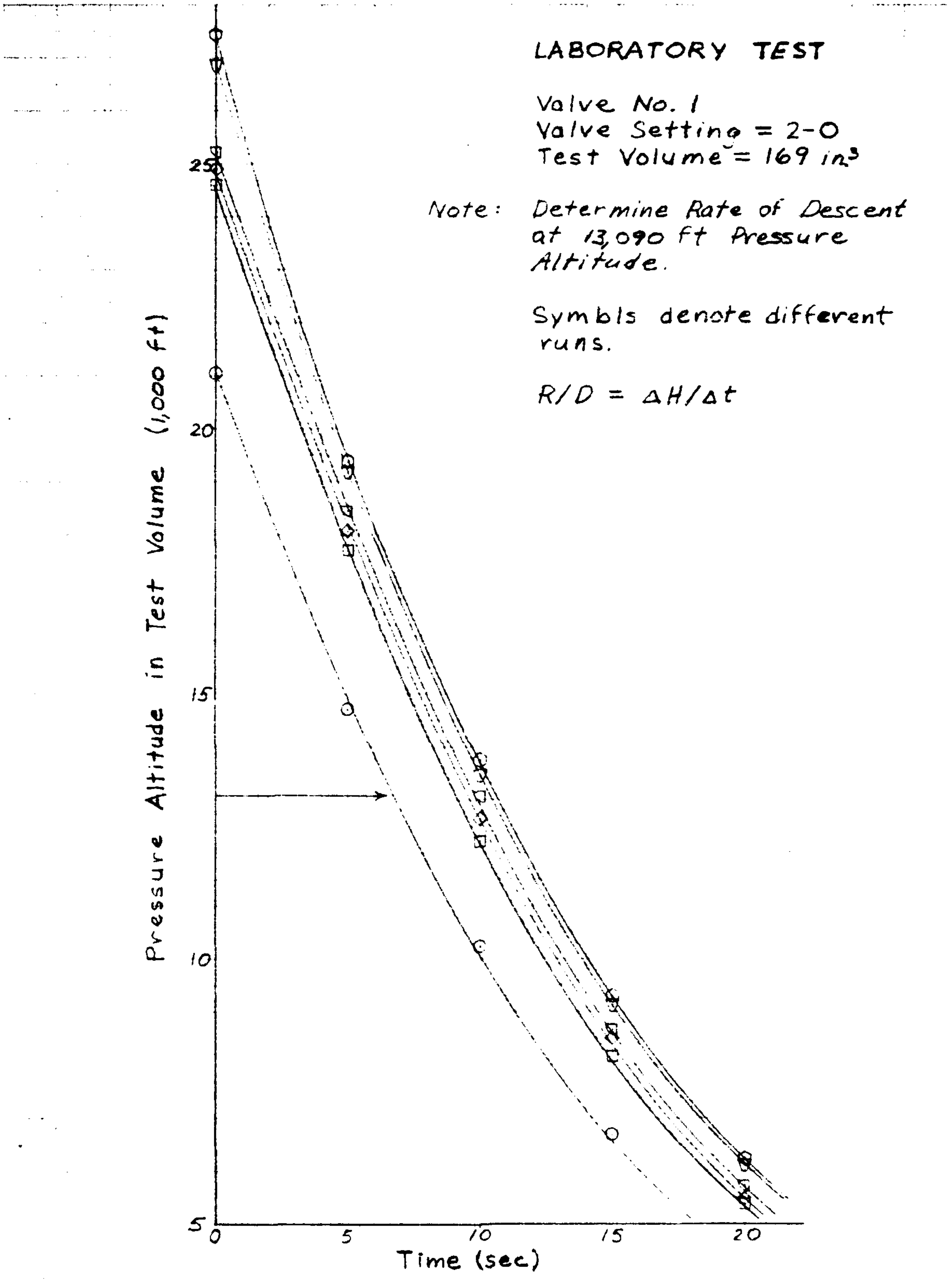


FIGURE 4 SAMPLE OF LEAK VALVE CALIBRATION DATA

The rate of descent of each set of data was determined by measuring the slope of a fairing through the data at the point of interest. The average rates of descent for each valve setting and test volume are shown in figure 5.

Laboratory tests were also performed to develop and verify a method of volume measurement. A test apparatus was set up as depicted in figure 5. In the laboratory the "unknown volume" was actually one of the test volumes of known size. The procedure used was as follows: equalize and record the pressure in the two volumes, change the pressure in the volume connected to the pump and record it, equalize the pressures in the volumes again and record it. A mass balance equation was solved for the unknown volume in terms of the reference volume and the three recorded pressures. A constant temperature model gave consistent results.

In order to determine the correct value for the "unknown volume" it was necessary to account for the volume of each piece of the apparatus including the valves, fittings, and lines. The pressure monitor volume was not known and could not be determined directly. However, the volume was calculated indirectly by two methods. In the first method, the mass balance equation was rewritten and the definition of unknown and reference volume was interchanged. Using the constant temperature model, the calculated value of the unknown volume was found to differ from the actual value by a constant which was taken to be the pressure monitor volume. Use of this computed volume with other laboratory data gave consistent results in the attempt to determine a system's internal volume. The pressure monitor volume was also determined by using it alone as the unknown volume. The results of the two methods for volume determination of the pressure monitor were consistent. The isothermal model of the process was found to give correct values for the unknown volume.

Tests concerning the effects of a leak in the pitot system were related only to the pilot's pitot system on the KC-135A type aircraft. For this reason the effects of pitot system volume were not considered.

Calibration data for the pitot leak valve No. 3 were obtained in the laboratory tests. The equipment set up depicted in figure 7 was used to collect the necessary information. Volume flow rates and pressure drop through the leak valve were recorded for several different pressures on the upstream side of the valve. The pressure drop was plotted against the calculated mass flow rate.

Aircraft Tests:

After the volume determination method was confirmed in the laboratory, the method was applied to the test aircraft according to the schematic in figure 6. When the volume of the pilot's static system was determined (156 cubic inches) it was used as the entry point in figure 5 to determine the rate of descent for each valve's setting used in the tests and for the specified pressure differential.

Leak rate tests were conducted on the test aircraft's pilot pitot system. The test equipment depicted in figure 7 was used to measure the rate of airspeed decrease due to a leak and the volume flow rate through the leak hole. The leak flow was generated by pumping a high pitot pressure into the pitot system (over 450 knots (kt) showed on the

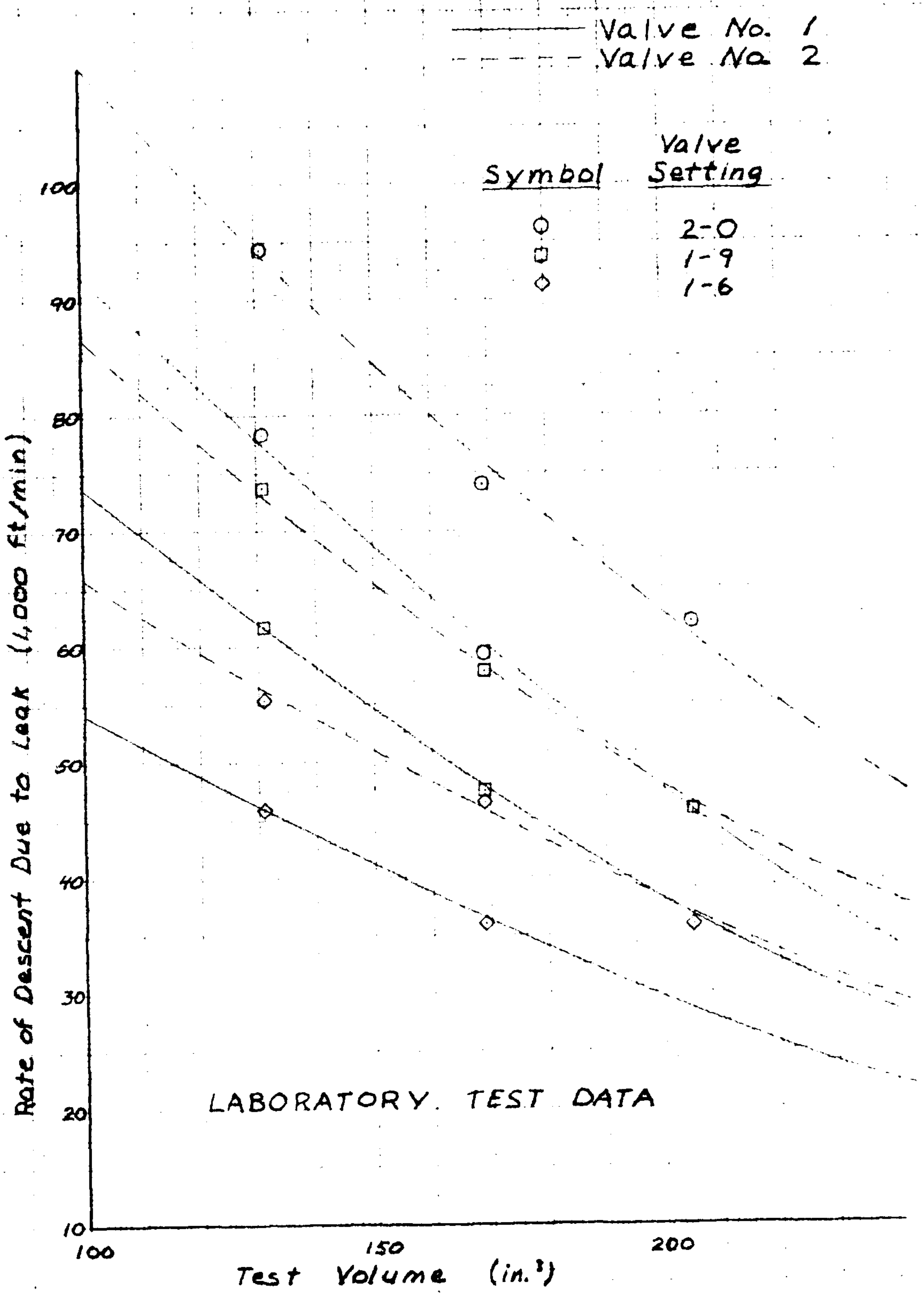


FIGURE 5 LEAK-INDUCED RATE OF DESCENT VARIATION WITH VOLUME

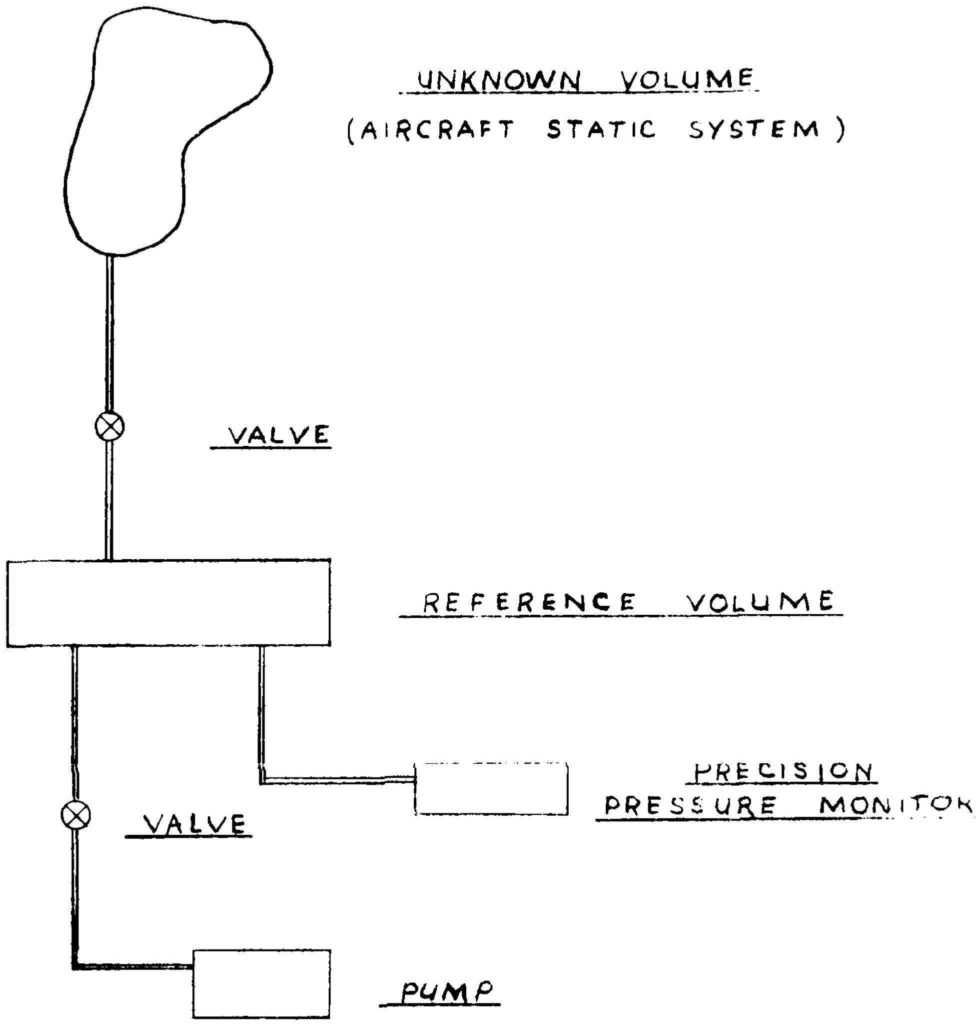
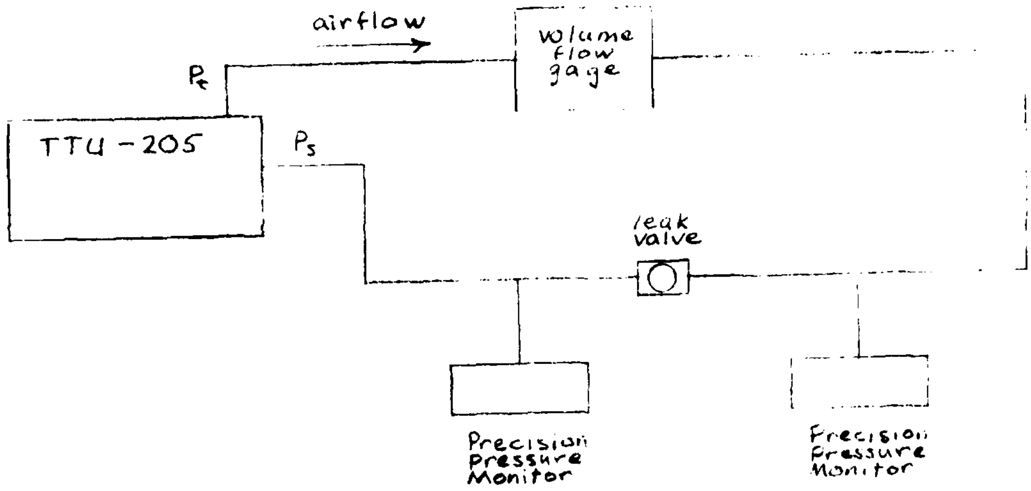
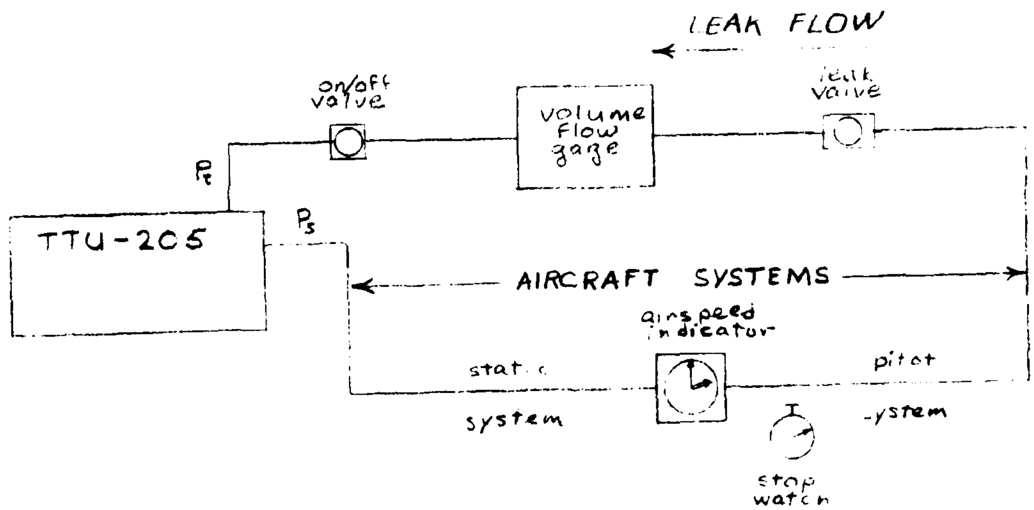


FIGURE 6 SCHEMATIC OF APPARATUS USED TO DETERMINE AN UNKNOWN VOLUME



LABORATORY TESTS



AIRCRAFT TESTS

FIGURE 7 SCHEMATICS OF EQUIPMENT USED FOR PITOT LEAK GROUND TESTS

airspeed indicator) and setting the pump at a low pitot pressure (50 kt) during the leak test. The rate of airspeed decrease measured on the pilot's airspeed indicator was plotted against the calculated mass flow rate.

Ground tests pertaining to pitot leaks were not repeated or duplicated. Thus, there was no obvious indication of repeatability or scatter in the measured parameters for any given conditions.

The pilot's and copilot's pitot-static systems were leak checked and leaks were eliminated until the leak criteria established for this project were achieved. The leak criteria for the pilot's pitot-static system was zero leak rate. The copilot's pitot-static system leaks were no greater than 50 feet per minute decrease in indicated altitude from 10,000 feet and 3 knots increase in airspeed in 5 minutes from 300 knots indicated when the pitot and static systems were pressurized to those starting values using a TTU-205 pressure test set.

FLIGHT TESTS

The flight test method used was termed no leak/leak in reference 2. With the aircraft stabilized at a specified speed and altitude on the copilot's instruments, instrument readings were recorded with the leak control valve off. Then the instrument readings were again recorded with one of the leak control valves on and the associated indexed leak valve set to a specified opening.

Leaks into the pitot and static systems were always made from the aircraft cabin with the cabin pressure higher than ambient. No attempt was made to leak out of a system into a compartment with pressure less than ambient.

Pneumatic altimeters were used for the first eight test flights. Analysis indicated that the data contained too much scatter to demonstrate the desired repeatability and expected trends. The electrical Hamilton Standard altimeters installed for the final five test flights presented a combination digital and discrete clock-face readout. The resolution of the clock-face presentation was 20 feet. Thus each measurement of the basic altitude data contained an uncertainty of 10 feet.

None of the airspeed indicators were replaced by pressure transducers. All airspeed error data was measured by the calibrated pneumatic airspeed indicators.

On the first leak test flight with pneumatic instruments, leak valve settings of 0-9, 1-0, and 1-3 were tested. However, the altimeter error magnitudes were not large enough to show trends. Scatter in the reduced data was too large. On the second leak test flight, settings of 1-6, 1-9, and 2-0 were used. This increased error magnitudes enough that some expected relationships were identifiable. However, these settings produced ground leak check rates of descent of 12,000 to 19,000 ft/min for valve No. 1 with the altimeter reading 10,000 feet and an airfield altitude of 2,300 feet (ΔP = 6.94 in. Hg.). The ground check leak rates were measured with the test instrumentation, including the additional tubing volume, installed. The test instrumentation approximately doubled the static system volume and thus significantly lowered the indicated rate of descent due to the leak. When

the digital altimeters were installed, flight tests continued using the larger leak holes. No tests were performed with smaller leak holes giving leak rates closer to the currently accepted leak rates.

During the first flight ten sets of data were recorded for each parameter of interest. With each succeeding flight the number of repetitions was reduced. Three sets of data were recorded for each parameter value on the last flight.

During the test it was confirmed that the primary parameters affecting altimeter error for a given system were leak size, leak location, and cabin differential pressure, ΔP_C. Cabin pressure was recorded by the extra altimeter at the navigator's panel. The pressure differential conditions used on the last series of flights are shown on figure 8.

Airspeed data were recorded for the conditions of no leak and leak through the static and total system leak valves. The primary parameters affecting airspeed errors due to a pitot system leak were leak size, airspeed, and cabin differential pressure. A leak-induced airspeed indicator error is caused by a pitot pressure error at the indicator. The pressure error is due to pressure loss mechanisms affecting the leak flow (system geometry and viscosity) and the relative locations of the leak and the indicator. When there is no leak flow, there can be no pressure error. Thus if the pitot (total) pressure equals the cabin pressure, there will be no flow through the hole and no error signal. Another representation of the same condition is that when impact pressure, q_C, (total minus static) equals cabin differential pressure, ΔP_C, (cabin minus static), there will be no error. Figure 9 shows the relationship of airspeed to cabin pressure differential for which there will be no airspeed error with a hole in the pitot system. The pitot leak test conditions are also indicated.

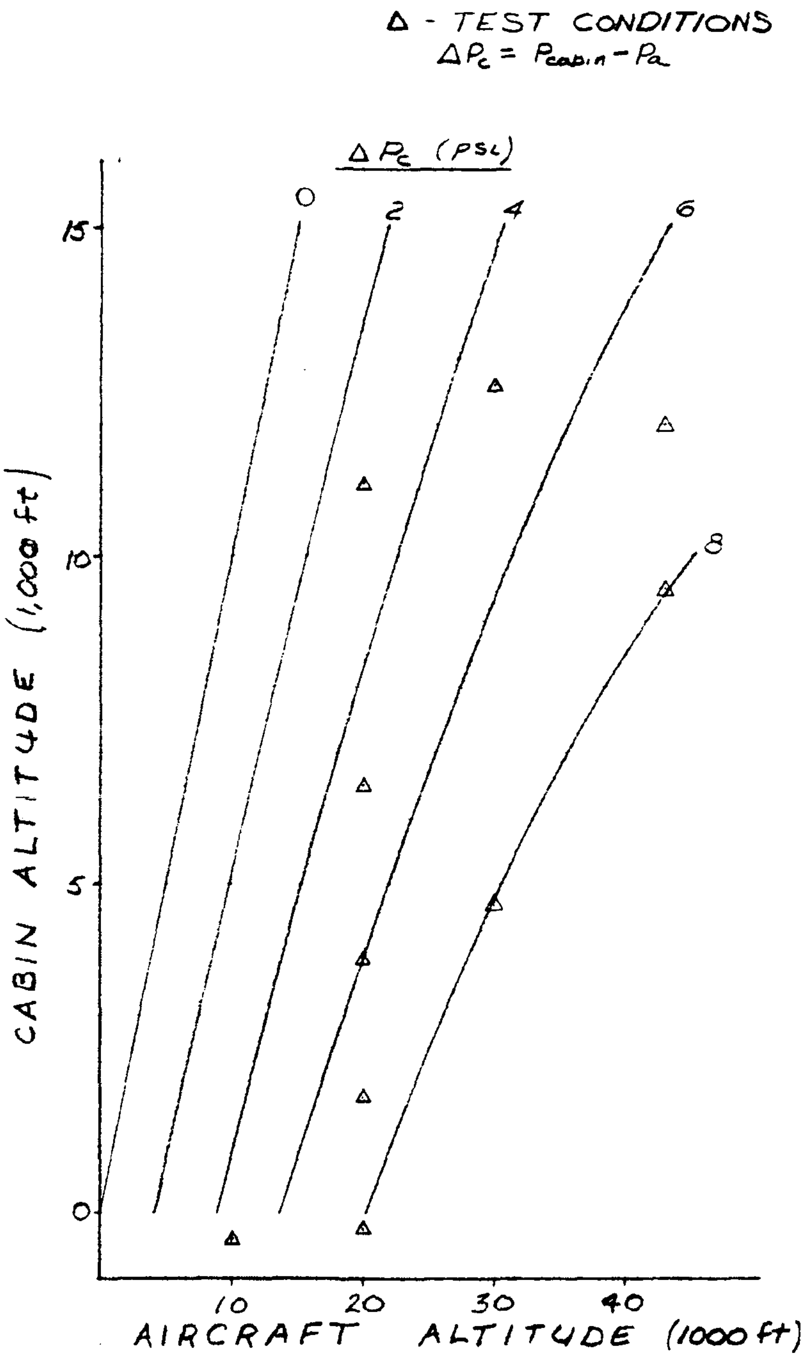


FIGURE 8 CABIN ALTITUDE SCHEDULE

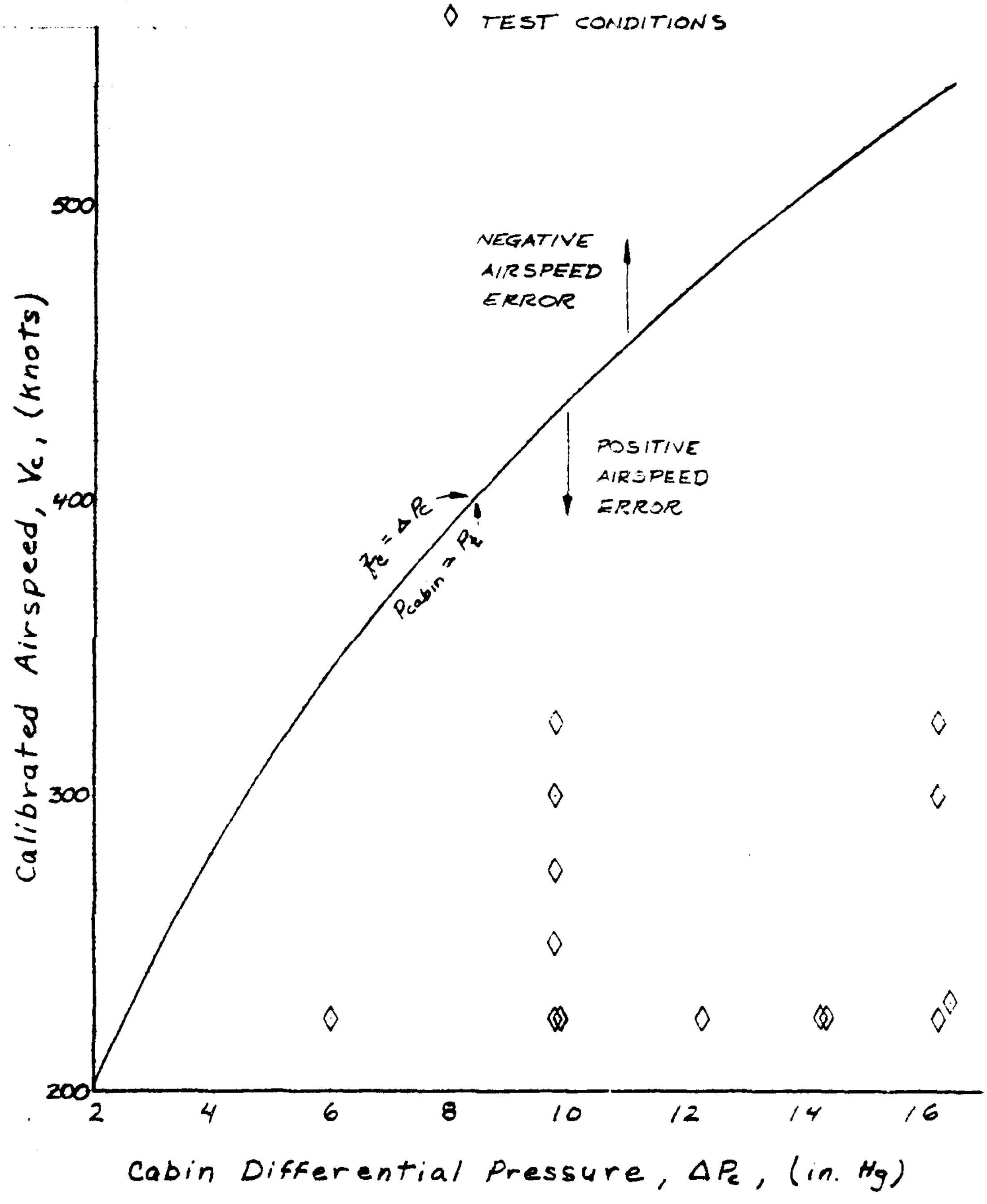


FIGURE 9 AIRSPEED VS. CABIN DIFFERENTIAL PRESSURE FOR NO AIRSPEED ERROR DUE TO A PITOT LEAK

TEST RESULTS

Analysis of data from the first series of flight tests had indicated that there was no definitive dependence of altimeter error upon varying airspeeds. After the installation of the digital altimeters, the first test flight again explored the effects of airspeed on the altimeter errors. The data (figure B1) indicated that increasing the airspeed caused a slight increase in the altimeter error. However, the effect was not considered significant enough to include airspeed investigation on subsequent flights most of which were flown at 225 kt indicated airspeed.

The static pressure error due to a leak increased with increasing Mach number (figure B2). Only the data from one flight was acquired at constant altitude (30,000 ft) and varying airspeed. The Mach number variation of the other data is due mainly to altitude variation. In addition to the pressure error variation with Mach number, four pairs of data points (see 43,000 feet data) indicate that the pressure error also increased with increasing flight altitude.

The mechanism for the pressure error increase was probably related to the variation of true airspeed (figure B3). The leak air flowing out the static ports probably disturbed the boundary layer, and possibly the free stream, flow pattern near the ports. The external flow disturbance probably caused a pressure increase at the static ports. In general, the boundary layer thickness at a point on a surface is inversely proportional to the square root or fifth root of the free stream velocity depending on whether the boundary layer is laminar or turbulent. Increasing airspeed, through boundary layer thinning or some other mechanism, may cause a pressure increase at the static ports so that the pressure error at the altimeter increases with airspeed.

The average altimeter error at each test point was converted to static pressure error. The static pressure error data is shown plotted against cabin differential pressure (ΔP_C) in figure B4 through figure B6. The fairings shown are linear regressions through all the data. With few exceptions the data show that the pressure error increased with increasing flight altitude for any cabin differential pressure.

Pihlgren (reference 2) found no static pressure error relation with changing flight altitude for fixed ΔP_C conditions. Pressure data showed some scatter but no altitude correlation. The different results of this study may result from the use of more sensitive instrumentation or from the different pitot-static sources used on the two test aircraft.

Certainly, part of the pressure error increase with altitude resulted from the increase in true airspeed. However, there are probably other effects involved since the altitude parameter appeared in figure B2 and figure B3.

The effects of leaks through valves No. 1 and No. 2 measured at altimeter No. 1 are compared on figure B7. The linear fairings were used to extract the data necessary to produce the final results in this report for the KC-135A aircraft. Due to insufficient data and the scatter in the data available, data from each test altitude were not faired nor were individual fairings used to produce the final results. The figure B7 plots show that leaks through valve No. 2

produced larger static pressure errors. The reason for the different effects was that valve No. 2 created a larger hole than valve No. 1 for any given valve setting (number of turns open). The larger hole size allowed a greater flow rate through the static system (figure 5). Additionally, it was assumed that pressure drop in the static system and flow rate through the line were linearly related. For that reason it was felt that the altimeter No. 1 data for valves No. 1 and No. 2 could be correlated.

The fairings through the altimeter No. 1 and No. 2 data for leaks through valve No. 1 are compared in figure B8. The data showed that the pressure in a part of the static system upstream from the leak location would reach the same pressure as that at the leak location. The upstream location is a part of the system through which there is no leak airflow.

The data and appropriate fairings for measurements at altimeters No. 1 and No. 2 with leaks through valve No. 2 are compared in figure B9. The difference between the pressures at the two altimeters is due to the pressure losses caused by the viscous resistance to the flow through the 100 feet of static line between the two altimeters.

Figure B9 shows that a leak at the altimeter case would cause a greater error than a leak at a location upstream which would cause flow through the line past the junction to the altimeter. A similar sized leak hole at a downstream location between the altimeter and the static ports would cause less error than if that leak occurred at the altimeter. Less pressure error would be transmitted to the altimeter because the shorter tubing length between the leak and the outlet would cause less viscous pressure loss. Thus, a leak at the altimeter can be expected to cause the greatest altimeter error.

The methods discussed in Appendix A and shown in figure A1 and figure A2 were used to create plots of altimeter errors for the parameters of significance in a production static system. Quadratic curves were fit through the data and the origin using a least squares routine to compute the coefficients of the equations. Examples of the derived data points and the quadratic fairings are shown in figure B10 and figure B11. The results pertain to leaks in the KC-135A pilot's static system.

Effects of different static system volume are shown in figure B12 through figure B15. The curves represent only the effect that system volume has on the leak check rate of descent. System configuration effects were not included. Since all the altimeter error values are based on the KC-135A tests, a different system configuration, with the same volume, could give different results; for example, a configuration causing greater resistance to leak flow (long static lines, smaller lines, or smaller static orifices) would create greater leak-induced altimeter errors. The curves were hand faired through data points derived as previously discussed. The 100 cubic inch value was chosen arbitrarily. The 156 cubic inch value represents the pilot's static system in the KC-135A. The 240 cubic inch value represents the production static system in the RF-4C aircraft. In support of a study of the sensitivity of the pitot-static systems on the AFFTC pacers, the volumes of the pitot-static systems on the RF-4C pacer were determined using the methods previously described. The production system volume was estimated by subtracting the estimated volume of the pressure transducer connected to it.

The fairings in figure C1 through figure C10 represent the predicted results for the leak-induced altimeter errors in the pilot's static system of a KC-135A. The expected trends are demonstrated. Greater altimeter errors are caused by increasing cabin pressure, increasing cruise altitude, and larger leak holes.

For cruise flight at 40,000 feet a cabin altitude of 8,000 feet can be maintained by a differential pressure (ΔP_C) of 16.69 in. Hg. For those conditions a leak test rate of descent of 20,000 feet per minute would not cause an altimeter error as large as the ±250 feet AIMS criteria.

The ±250 feet AIMS criteria is the allowable altitude error due to all causes. In order to establish a leak rate criteria for an aircraft which would meet the AIMS criteria, the altitude error of the particular aircraft must be known because the allowable leak-induced error depends on the existing error due to other causes. If an aircraft had an altimeter error of -250 feet at some particular cruise altitude, then no leak-induced error could be allowed. However, if the aircraft exhibited a constant error of +250 feet at all altitudes, then the static system could leak at a rate which would create a -500 foot error at the maximum cruise altitude and cabin pressure conditions.

If the results of this report were applied to the development of leak rate criteria to take advantage of the available AIMS criteria "error budget," the allowable leak rate might be 20,000 feet per minute (2,000 foot altitude band in 6 seconds). However, if it is assumed that leaks develop at and because of loose fittings, a leak rate approaching 20,000 ft/min would probably cause more concern for the physical integrity of the system and the associated safety aspects of a complete failure than any altimeter error which might result from the leak.

Current leak rate criteria will result in reasonably small altimeter errors on most aircraft and the physical integrity of the systems should not be a concern. If maintenance of pitot-static system integrity to current leak rate criteria causes an excessive expenditure of time and money, the criteria for most aircraft could probably be relaxed. However, any change to existing criteria should be accomplished with an understanding of existing altitude error of the aircraft and the postulated leak effects based on the aircraft's static system volume. It might be possible to standardize the leak criteria for all aircraft in the inventory. The most probable limiting case would be the aircraft with large volume pitot-static systems and large negative altitude errors in their altimetry systems.

Airspeed errors result from leaks in both the pitot and the static systems. Leaks from a pressurized cabin into the static system cause negative airspeed errors, i.e., lower indicated airspeeds for leak conditions. Figure B16 is a correlation of expected airspeed errors and leak-induced altimeter errors for specified altitudes on the basis of the pressure error in the static system due to a leak. The fairings are based on the equations relating airspeed and altitude to pressure in the standard atmosphere. The curves show that for any given static leak condition, the airspeed error decreases with increasing airspeed. Increasing cabin pressure differential causes greater airspeed error because of increased pressure error.

Pitot system leaks cause airspeed errors which depend both on airspeed and cabin pressure differential. The airspeed effect on airspeed errors for particular cabin pressure differentials is shown in figure C11 through figure C14. The plots apply to the KC-135A pilot's airspeed indicator. Increasing airspeed and decreasing hole size caused decreasing airspeed errors for any given cabin differential pressure. The figures also show the effects of varying the airfield altitude at which the leak check is performed.

The cabin pressure differential effect on airspeed errors for certain airspeeds is shown in figure C15 through figure C17. Those plots also apply to the KC-135A pilot's system. The fairings show that increasing cabin differential pressure causes increased airspeed errors for given airspeed.

Variables such as leak location and system volume were not investigated in the pitot leak tests. However, effects similar to those shown for the static leak investigation (figure B8 and figure B9) would probably occur. A leak in the airspeed indicator fittings would probably cause the greatest errors. The leak check airspeed decrease rate would be higher for a smaller volume pitot system if the leak hole and test conditions were similar.

CONCLUSIONS AND RECOMMENDATIONS

The major variables affecting altimeter errors due to static system leaks were leak hole size and the difference between cabin and ambient pressure. Airspeed errors were affected by the same variables as well as airspeed. Ground test leak rate was found to depend on leak hole size, system volume, and the pressure differential at which the test was conducted.

In general, the leak effects tests showed that small pitot-static leaks do not result in significant altitude or airspeed errors. Significant errors can result as the leak rate increases to levels at least an order of magnitude greater than current leak rate criteria will allow. A static pressure system leak check criteria based solely on permissible altitude error might allow leaks which are unacceptably large when system integrity is considered. The continued use of current Air Force pitot-static system leak check criteria should result in negligible airspeed and altitude errors. The leak rate criteria for any aircraft could probably be relaxed if maintenance man-hours expended to stop leaks were found to be excessive. Adjustments could also be made in the interest of standardizing leak check criteria for all Air Force aircraft. Any changes to the present procedures must consider that the allowance for leak-induced altitude errors depends on the existing altitude error curves for static system installations as they relate to the AIMS criteria.

1. Current Air Force leak rate criteria should be maintained.

2. Leak rate criteria for new aircraft and changes to the current criteria used for Air Force aircraft should be based on the aircraft's altitude error curve, its relation to the AIMS criteria, and the effect that the static system volume will have on the relationship between the leak rate criteria and the expected altitude error.

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2. Pihlgren, Wayne D., Effect of Static System Leakage on Aircraft Altitude Measurements, FTC-TIM-71-1005, Flight Test Technology Branch, Edwards AFB, California, 1971.

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4. Technical Manual, General Airplane, USAF Series KC-135A, EC-135C, RC-135C Aircraft, T.O. 1C-135(K)A-1, 15 February 1964.

APPENDIX A

DATA ANALYSIS METHODS

Due to the original desire to produce a generalized model of leak-induced altimeter errors which could later be applied to any aircraft type, a number of ground tests were performed which might not have been necessary to define the static system leak effects on just the KC-135A aircraft type. Depicted in figure A1 is the process by which data collected in the laboratory and during aircraft ground tests were correlated to produce generalized effects and unique values of the principal parameters (figure 5) characteristic of ground leak checks.

Flight test data used to generate the final altimeter error results presented in this report consisted of instrument corrected pressure altitudes for no leak and leak conditions and the associated cabin pressure altitudes. The altimeter readings were converted to pressures (figure A2). From each set of altimeter data the equivalent pressure differential was computed, i.e., cabin differential pressure, $\Delta P_c = P_{cabin} - P_a$, and leak-induced altimeter pressure error, $\Delta P_e = P_{ic\ leak} - P_{ic\ no\ leak}$. The computed pressure errors were then plotted against the associated cabin differential pressures (figure A2). Data for the final plots were obtained from the fairings through the pressure error plots.

The predicted altimeter errors for the KC-135A aircraft type shown in this study were generated by combining the results of the ground and flight tests (figure A2). Cabin differential pressure, ΔP_c, was one of the significant parameters. A value of altimeter pressure error, ΔP_e, was obtained for each valve setting and the selected ΔP_c value from the fairings through the measured data. Each valve setting was converted to a leak check rate of descent by way of the ground test calibrations. Each pressure error was converted back to a series of altimeter errors, one for each specified cruise altitude, by using the equations for the standard atmosphere or tabular data of same. Thus, the final plots of altimeter error as a function of leak check rate of descent could be plotted for the parameters of cruise altitude and cabin differential pressure.

The data resulting from ground tests on the leak valves and test volumes was correlated by using a fixed pressure differential between ambient pressure and pressure inside the test volume. To extend the methods and results of this program to a leak check on a KC-135 aircraft at some other location the check should simulate the conditions (primarily pressure differential) used to obtain the test data. Rather than evacuate the static system to an indicated pressure altitude of 10,000 feet, the static system should be evacuated so that the leak check can be accomplished at an indicated pressure altitude corresponding to a pressure differential of 9.344 in. Hg. Figure A3 shows the schedule which should be followed to maintain this pressure differential. For an airfield pressure altitude of 2,300 feet, for example, the leak check should be accomplished at an indicated pressure altitude of 13,150 feet (using an altimeter setting of 29.92).

The airspeed errors recorded for static system leaks were not used to develop a model for predictions of these errors for any arbitrary leak. Instead the equations relating pressures to calibrated airspeed

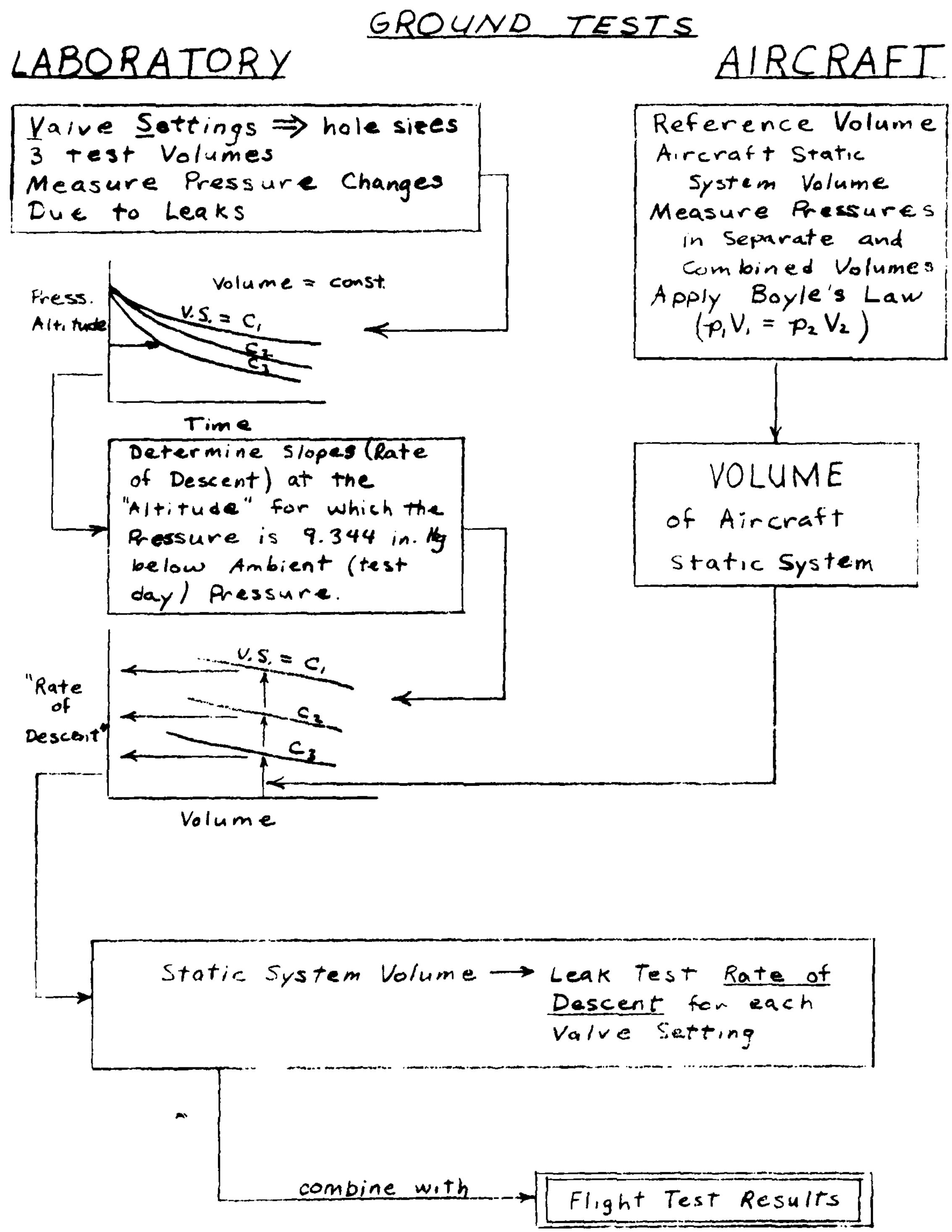


FIGURE A1 DEFINITIONS AND FLOW CHART FOR STATIC LEAK GROUND TEST DATA ANALYSIS

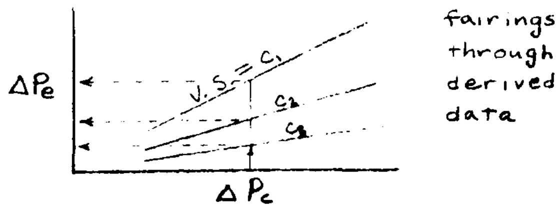
FLIGHT TESTS

Valve Settings $\Rightarrow$ hole sizes
Vary Altitude $\rightarrow$ P_a Varies
Vary Cabin Pressure, P_{cabin}

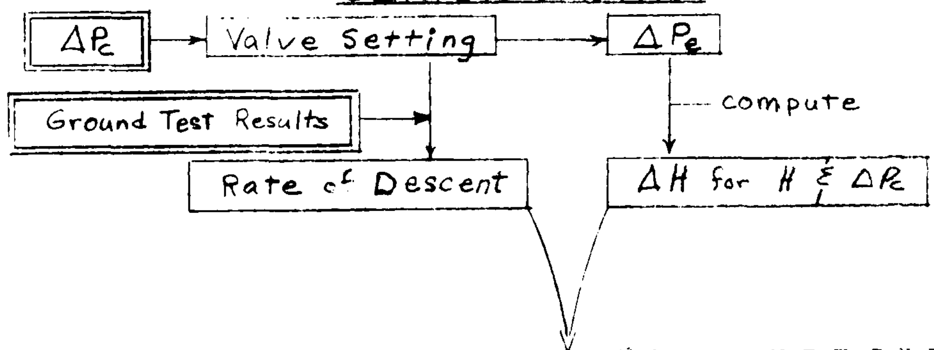
Cabin Differential Pressure; $\Delta P_c = P_{cabin} - P_a$

Leak-Induced Altimeter Error; $\Delta H = H_{ic_{leak}} - H_{ic_{no\ leak}}$

Computed Pressure Error Corresponding to Altimeter Error; $\Delta P_e = P_{ic_{leak}} - P_{ic_{no\ leak}}$



COMBINE DATA



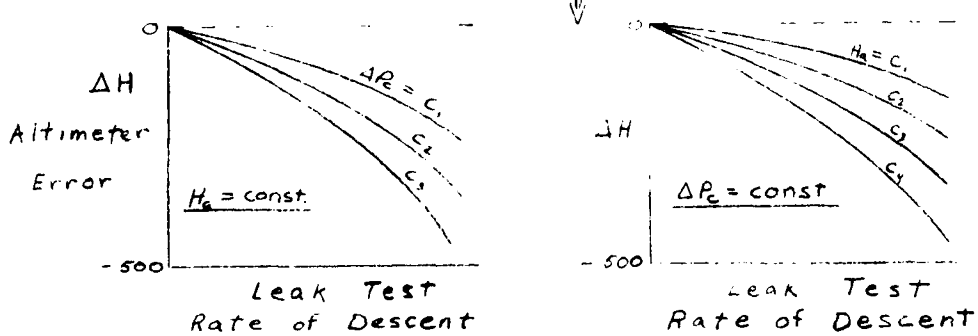


FIGURE A2 DEFINITIONS AND FLOW CHART FOR FLIGHT TEST DATA ANALYSIS AND DATA CORRELATION FOR STATIC LEAKS

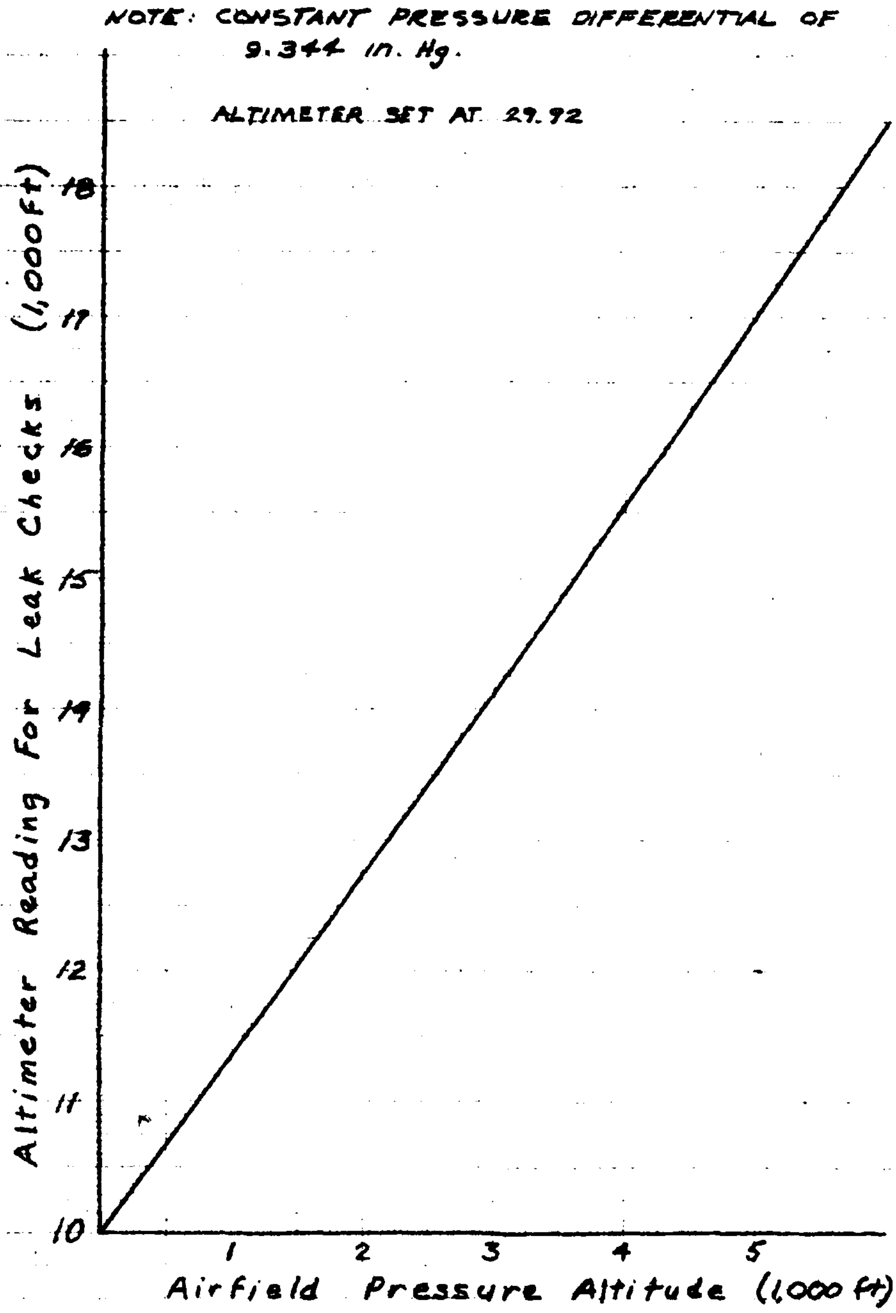


FIGURE A3 RECOMMENDED CONDITIONS FOR STATIC LEAK CHECK

and pressure altitude were used to relate airspeed errors to altimeter errors for particular pressure errors, airspeeds, and altitudes.

Tests to determine the effects of leaks in the pitot system were designed to apply specifically to the pilot's pitot system on the KC-135A aircraft. Tests to establish a generalized model based on system volume were not conducted.

Ground test data was plotted according to the description shown in figure A4. The data measured in the laboratory tests were plotted as computed mass flow as a function of pressure drop across the leak valve for particular values of pressure at the volumetric flow meter and leak valve setting (figure A5 through figure A7). The resulting fairings were then cross plotted as pressure drop as a function of pressure at the flow meter for particular mass flow rates and valve settings (figure A8 through figure A10).

The leak test data measured during ground tests on the test aircraft pitot system consisted of airspeeds and pressure altitudes pumped into the pitot-static system, volumetric flow rates, and times for the indicated airspeed to decrease through specified bands about the test conditions. Initially a mass flow rate was calculated for each test by assuming that the pressure at the flow meter was the value determined by the airspeed dialed into the TTU-205 pressure test unit during each leak (50 kt). The TTU-205 was assumed to be an ideal sink (evacuator). The pressure at the flow meter was not independently measured. The computed rate of airspeed decrease due to each leak was plotted as a function of the computed mass flow rate (figure A11).

It was assumed that the ground test data and flight test data could be correlated by choosing a pressure drop across the leak valve (corresponding to a q_c or V_c as the leak check standard), by determining a mass flow for each valve setting and thus predicting the leak check rate of airspeed decrease. This final parameter value would be plotted against the airspeed errors determined from the flight test data for the chosen valve setting and the other parameters involved.

The aircraft pitot leak tests were conducted under conditions which were assumed to create a pressure drop across the leak valve of eight in. Hg. Application of this value to the laboratory data indicated that the mass flow should have been higher than the values which were calculated for the conditions assumed for the aircraft leak tests (figure A8 through figure A10). Since the results of the two different tests were expected to be similar for given conditions of pressure, pressure drop, and valve setting, the differences between the mass flow predicted by the laboratory data and the calculated results were attributed to the pressures assumed in the aircraft tests. Thus it was suspected that the TTU-205 test unit was unable to evacuate the test apparatus rapidly enough to maintain the eight in. Hg pressure drop across the leak valve. The calculated pressure at the flow meter was based on test total pressure (from V_c) and assumed valve pressure drop.

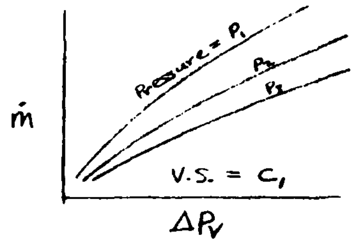
The aircraft leak test data (mass flow at assumed pressure) was plotted on the cross plots of the laboratory mass flow fairings (figure A8 through figure A10). The valve pressure drop interpreted for each data point was considerably below the value of eight in. Hg used in the calculations.

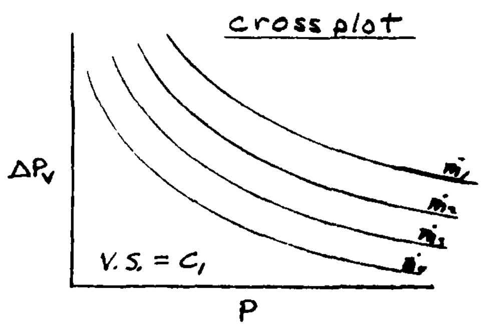
The mass flow computations were corrected by appplying a pressure

GROUND TESTS

LABORATORY

Valve settings ⇒ hole sizes
measure volume flow rates
and pressure drop across
leak valve (ΔP_v)
compute mass flow rate

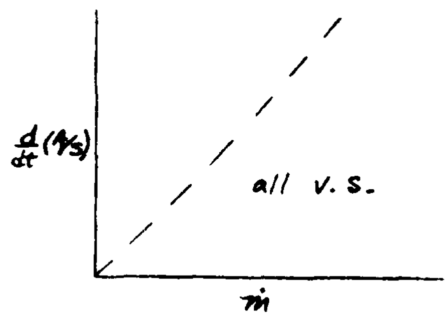




AIRCRAFT

Valve Settings ⇒ hole sizes
establish test P_t
leak to low P_t setting → ΔP_v
measure volume flow and
time for airspeed to
decrease through a band
compute mass flow rate
using volume flow and
low P_t value.

plot:
- $\dot{m}$ vs P on crossplot of lab data
- $\frac{d}{dt}(A/S)$ vs $\dot{m}$



CORRELATION

On crossplot, ΔP_v values of aircraft data
($\dot{m}$, P) were lower than assumed
$\therefore$ low P_t was wrong
correct P by ΔP_v difference
compute corrected mass flow; $\dot{m}_{corr} = f(\dot{v}, P_{corr})$

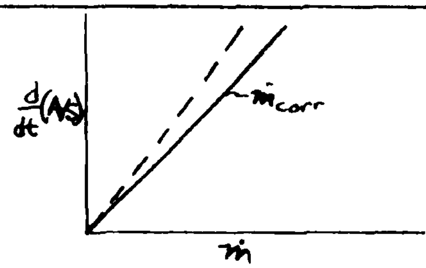


FIGURE A4 DESCRIPTION OF ANALYSIS OF PITOT LEAK GROUND TEST DATA

LABORATORY DATA

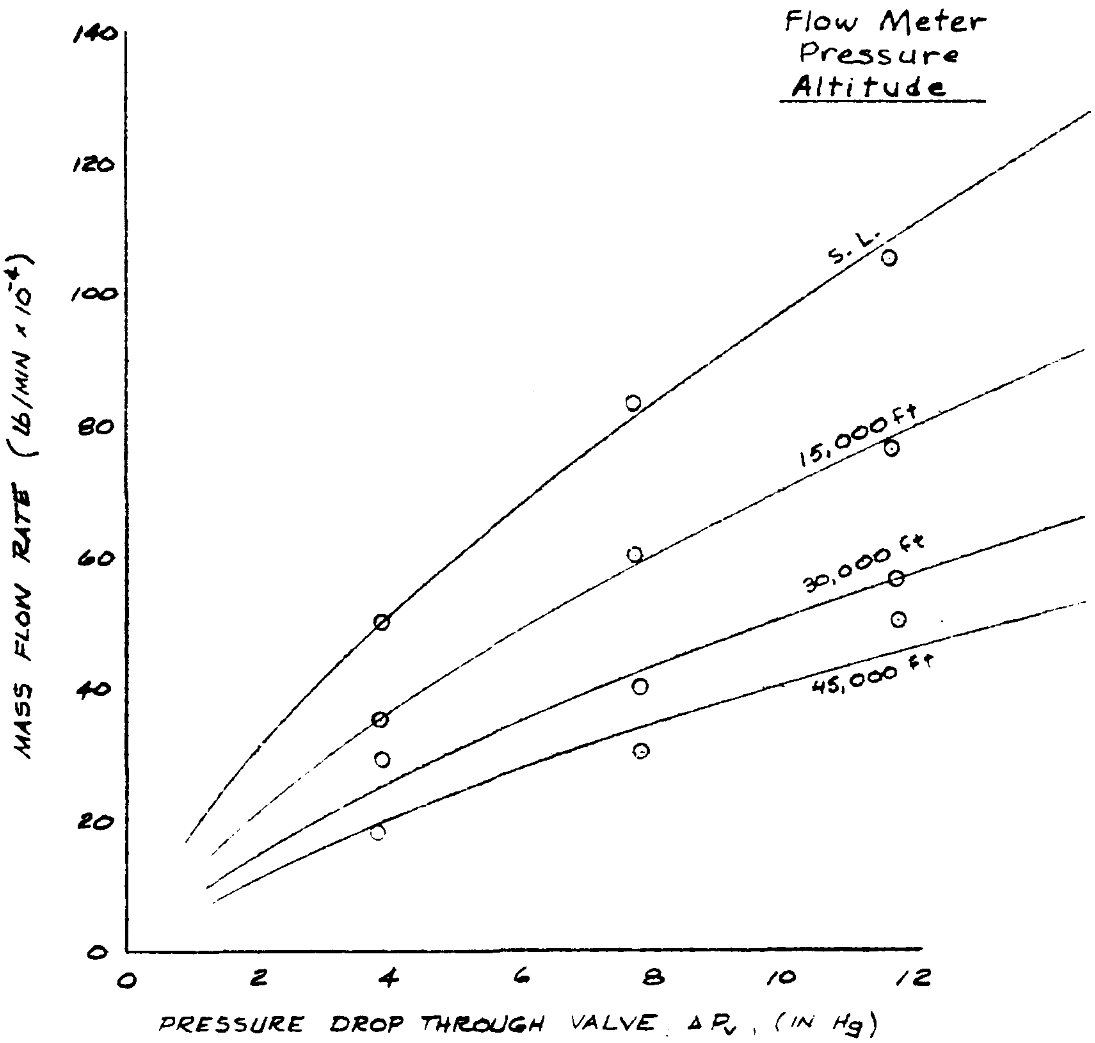


FIGURE A5 MASS FLOW RATE VS VALVE PRESSURE DROP FOR CONSTANT FLOW METER PRESSURE, VALVE SETTING = 1 - 6

LABORATORY DATA

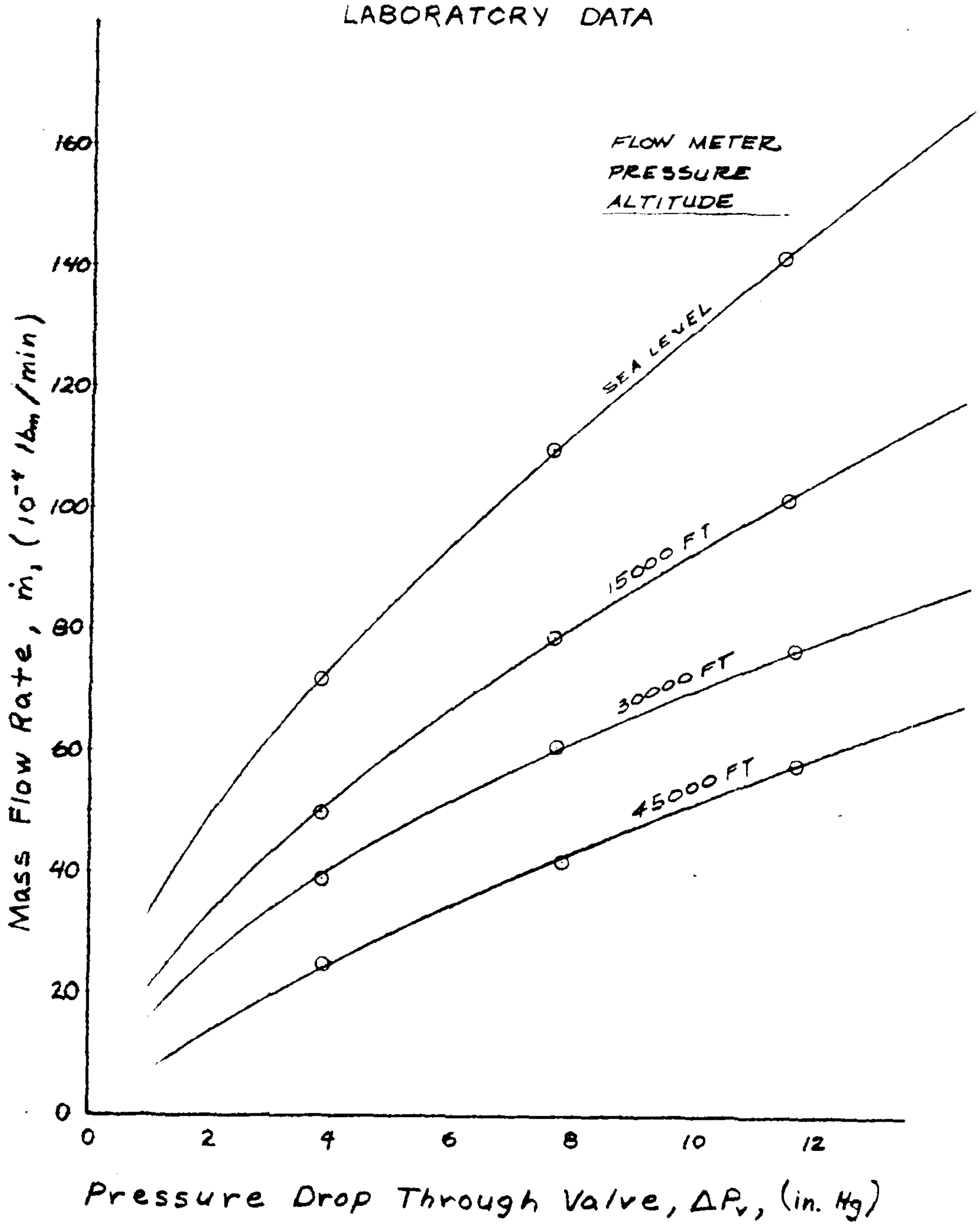


FIGURE A6 MASS FLOW RATE vs VALVE PRESSURE DROP FOR CONSTANT FLOW METER PRESSURE, VALVE SETTING = 1-9

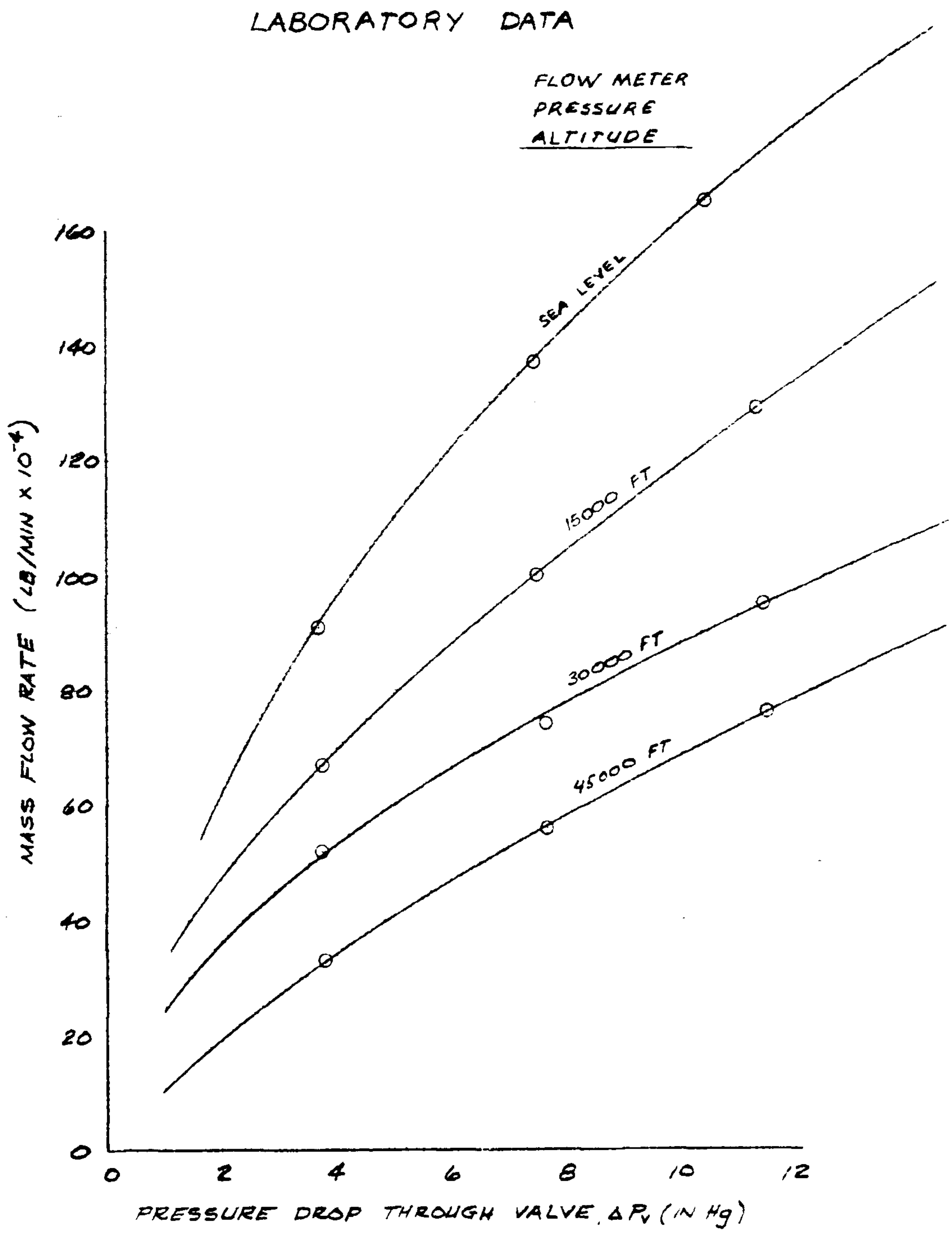


FIGURE A7 MASS FLOW RATE VS. VALVE PRESSURE DROP FOR CONSTANT FLOW METER PRESSURE
VALVE SETTING = 2-0

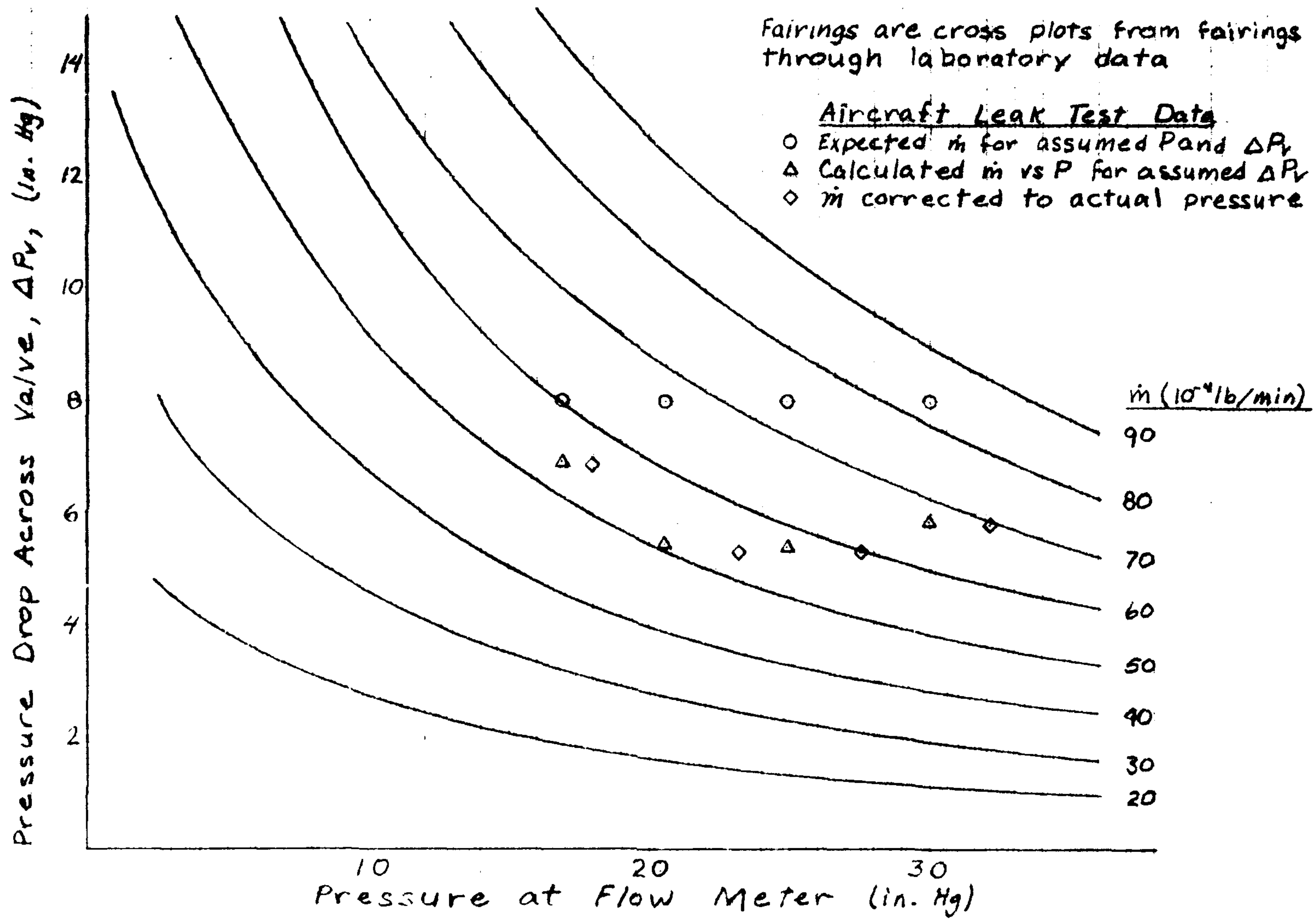


FIGURE A8 CONSTANT MASS FLOW FAIRINGS THROUGH VALVE PRESSURE DROP vs FLOW METER PRESSURE DATA, VALVE SETTING = 1-6

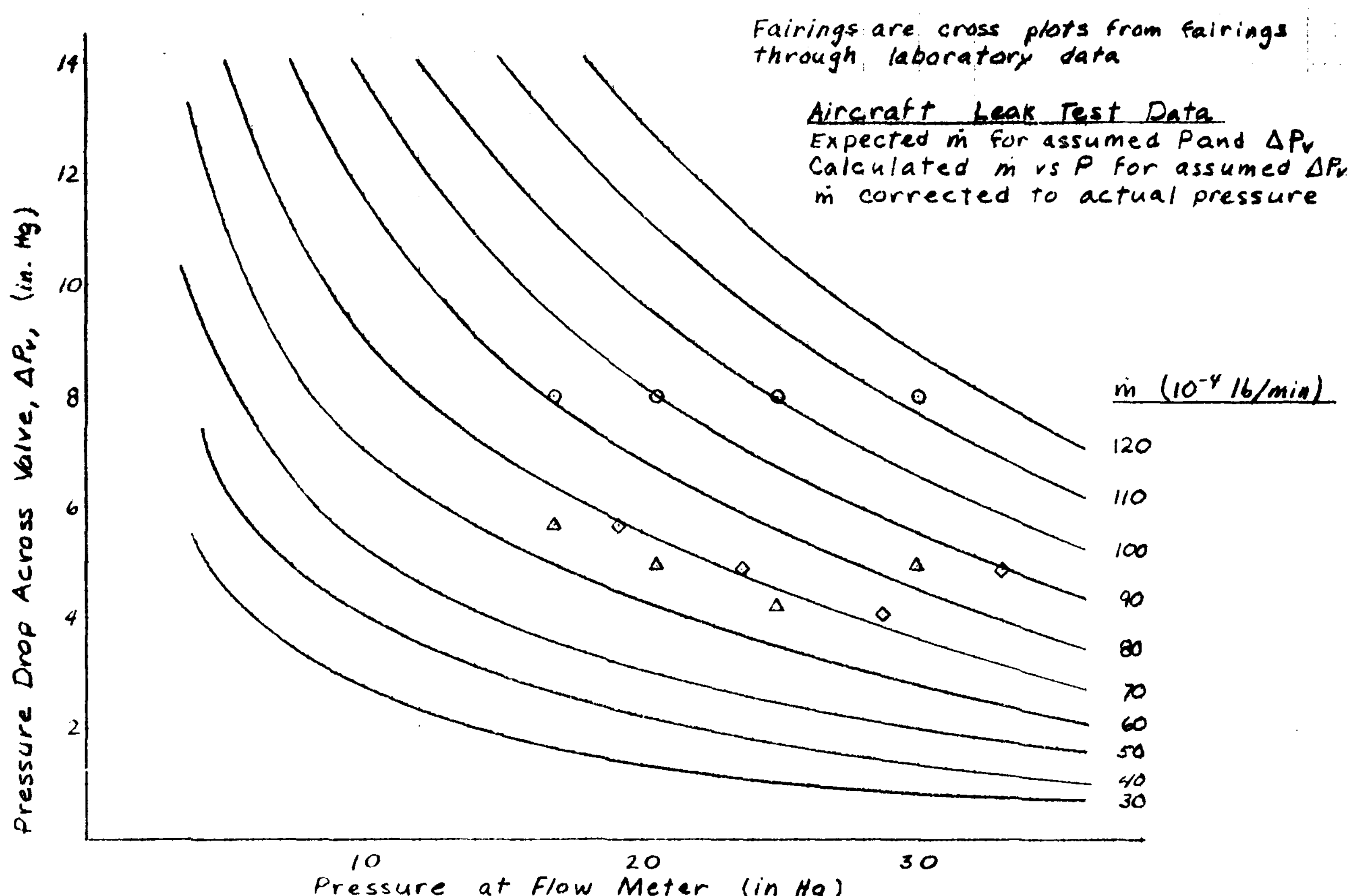


FIGURE A9 CONSTANT MASS FLOW FAIRINGS THROUGH VALVE PRESSURE DROP vs FLOW METER PRESSURE DATA, VALVE SETTING = 1-9

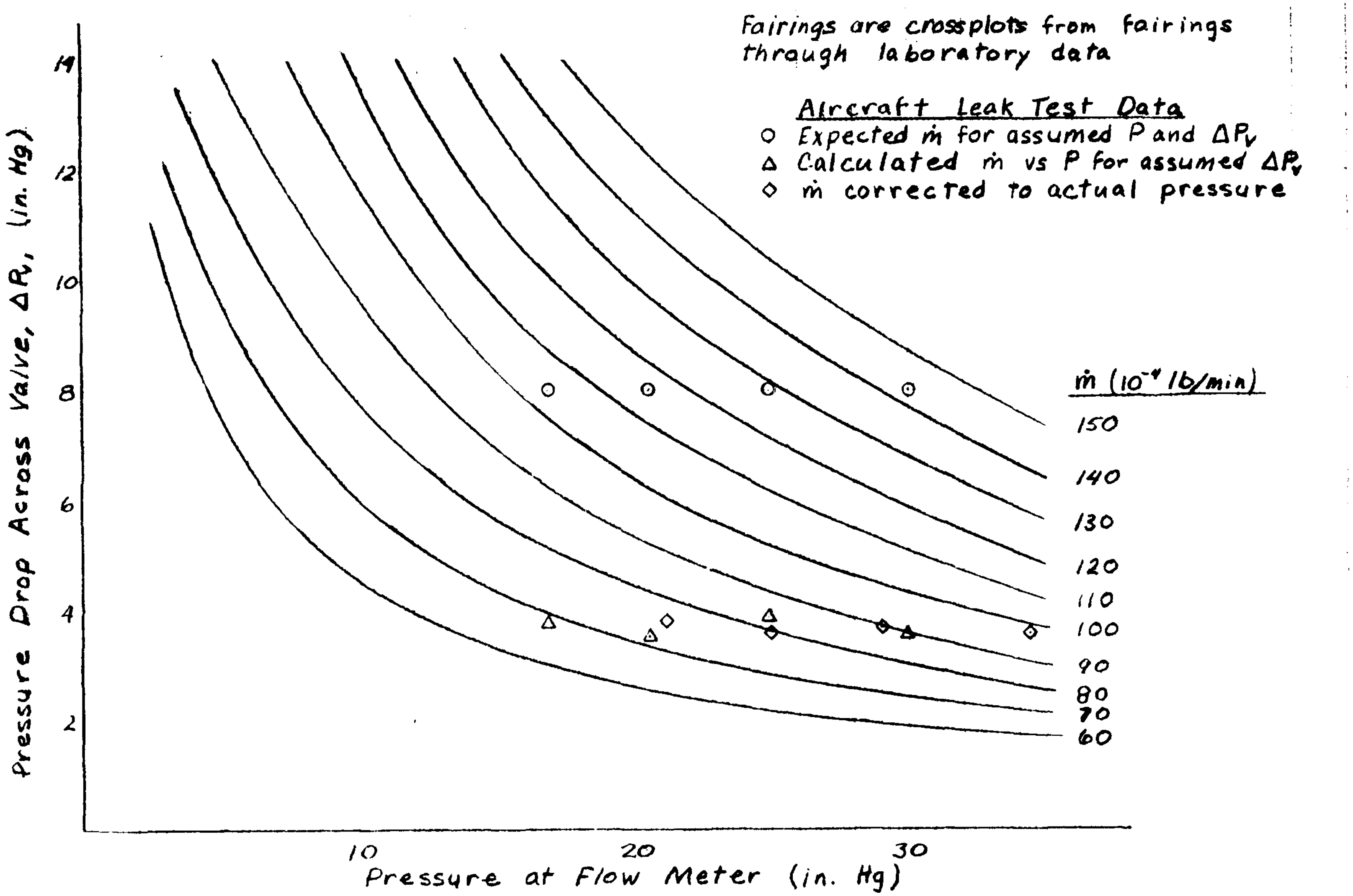


FIGURE A10 CONSTANT MASS FLOW FAIRINGS THROUGH VALVE PRESSURE DROP vs FLOW METER PRESSURE DATA, VALVE SETTING = 2-0

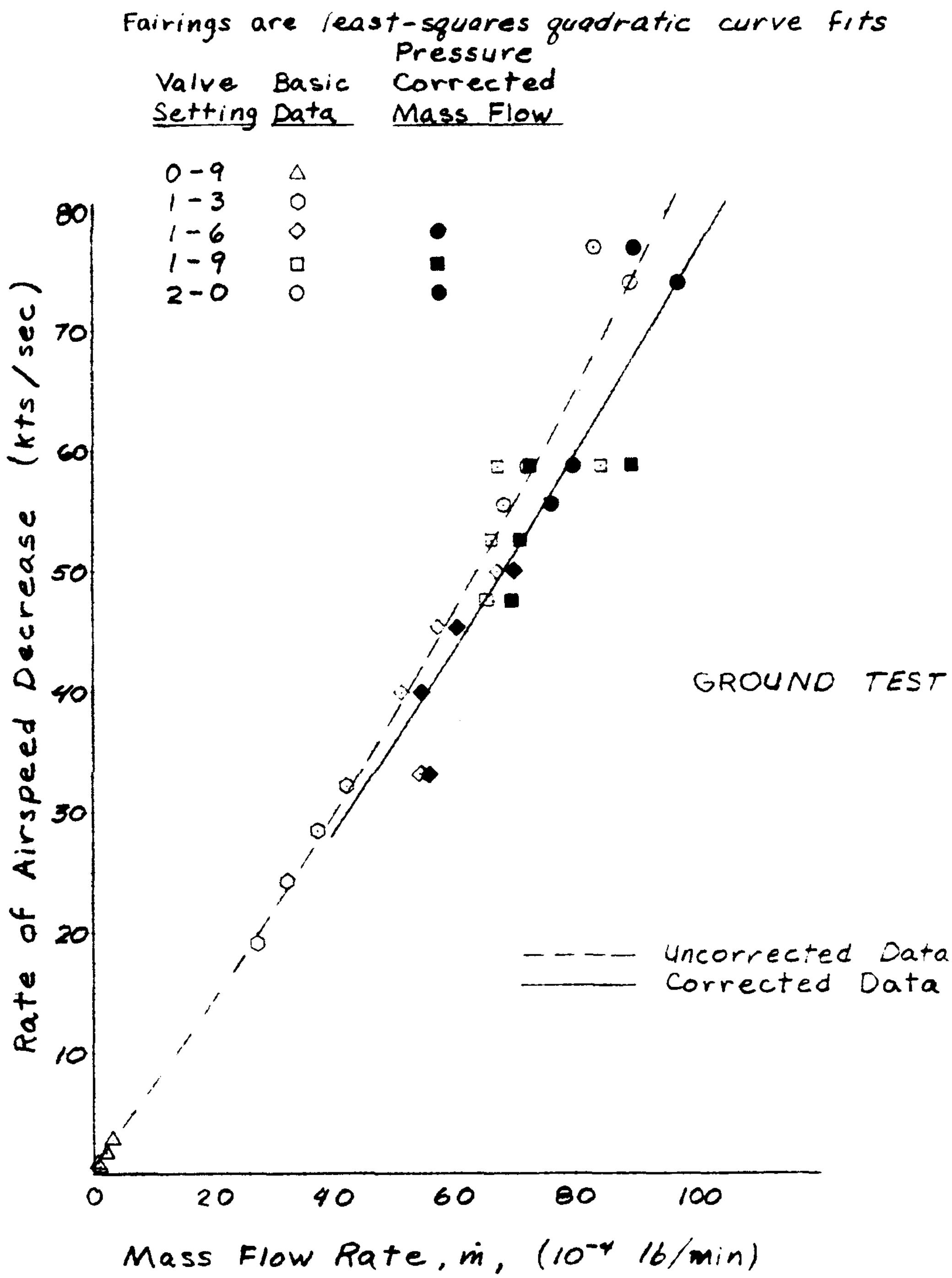


FIGURE A11 LEAK TEST RATE OF AIRSPEED DECREASE vs MASS FLOW RATE FOR TEST PITOT SYSTEM

correction to each test condition based on the difference between the assumed and plotted valve pressure drops. The plotted lower pressure drops for the computed mass flows implied that the pressure at the volume flow meter was higher than expected. After computing the corrected pressure conditions at the volume flow meter, a new set of pressure dependent volume flow correction factors were determined. New corrected volume flow rates and densities were computed. From those values a set of corrected mass flow rates were computed. The corrected mass flow rates were plotted on the laboratory cross plots (figure A8 through figure A10) and as the leak test rate of airspeed decrease against mass flow rate (figure A11).

Since the leak test data was not measured under consistent pressure conditions, it was necessary to assume that the laboratory data fairings represented the pressure and mass flow relationships for any given controllable conditions in a leak test on the aircraft. That is, for given conditions of pressure and pressure drop, the mass flow through the leak hole could be interpolated from the cross plots of lab data.

Flight test airspeed data consisted of instrument corrected airspeeds for no leak and leak conditions and the associated cabin and flight pressure altitudes. The altitude data was converted to cabin differential pressure, $\Delta P_C = P_{cabin} - P_a$, as for the static system leak tests (figure A12). The airspeeds were converted to impact pressure, q_{cic}, and the airspeed errors were converted to the equivalent total pressure errors, $\Delta P_e = q_{cic\ leak} - q_{cic\ no\ leak}$. The total pressure error, ΔP_e, was then plotted against the pressure differential between cabin pressure and the no leak total pressure, $\Delta P_T = P_{cabin} - P_{tic\ no\ leak} = \Delta P_C - q_{cic\ no\ leak}$ (figure A13).

For the purposes of this report the ground test data was correlated by using a pressure drop of 4.5 in. Hg and pressures of 29.92 in. Hg (sea level standard pressure) and 24.90 in. Hg (5,000 feet standard pressure). The pressure drop of 4.5 in. Hg is the leak check q_c condition (total minus static, hence pressure differential) which is obtained by sealing a pressure in the pitot system which causes a calibrated reading of 300 kt on the airspeed indicator with the static system exposed to ambient pressure. Since the data was affected by the static pressure at the flow meter, the results were generated by assuming two pressure conditions; sea level and 5,000 feet in the standard atmosphere. The 300 kt leak check condition was used because the results fall within the range of data measured in the aircraft leak tests.

The procedure (see figure A14) used to correlate the ground test data was to enter the lab data cross plots at the specified pressure drop and static pressure (4.5 in. Hg and 29.92 in. Hg or 24.90 in. Hg) and interpolate a mass flow rate for each valve setting. Then the expected rate of airspeed decrease for each mass flow rate was determined from the fairing through the aircraft leak test data on figure A11.

The predicted airspeed errors for a leak in the pilot's pitot system in a KC-135A aircraft which are shown in this study were generated by using the results of the ground and flight tests (figure A14). The primary parameters affecting the magnitude of the airspeed errors were cabin pressure differential (ΔP_C), impact pressure (q_c), and the leak hole size. For given conditions of ΔP_C and q_c, the pressure drop across the leak hole, ΔP_T, can be computed. For each value of ΔP_T thus chosen, the fairings through the ΔP_e vs ΔP_T flight test data enable one value of

ΔP_e to be determined for each valve setting used. The pitot pressure errors, ΔP_e, thus determined were converted to airspeed errors, ΔV, based on the airspeed chosen. Each valve setting was converted to a leak check rate of airspeed decrease based on the ground test calibrations. The computed ΔV values for each valve setting were plotted against the leak check parameter and a curve was faired through the points.

The ground test data was utilized by determining the effects of a 4.5 in. Hg pressure drop across the leak valve. A calibrated airspeed of 300 kt results when the difference between total and static pressure is about 4.5 in. Hg. Thus the pitot leak results of this report can be applied to KC-135 pilot's pitot systems configured like the test system if the leak check is performed with the pitot system pressurized so that the airspeed indicator reads 300 kt for the static system at ambient pressure. This condition would develop 4.5 in. Hg pressure differential across any leak hole.

FLIGHT TESTS

Valve Settings $\Rightarrow$ hole sizes
vary altitude $\rightarrow$ P_a varies
vary cabin pressure $\rightarrow$ P_{cabin}
vary speed $\rightarrow$ q_c $\rightarrow$ P_t varies
Define:
Cabin Differential Pressure: $\Delta P_c = P_{cabin} - P_a$
Leak-Induced Airspeed Error;

$$\Delta V = V_{ic\,leak} - V_{ic\,no\,leak}$$

Total Pressure Error for Airspeed Error;

$$\Delta P_e = P_{t\,leak} - P_{t\,no\,leak}$$

$$\Delta P_e = q_{c_{ic}\,leak} - q_{c_{ic}\,no\,leak}$$

Pressure Differential between Cabin & Pitot system;

$$\Delta P_T = P_{cabin} - P_{t\,no\,leak}$$

$$\Delta P_T = \Delta P_c - q_{c_{ic}\,no\,leak}$$

DATA PLOT

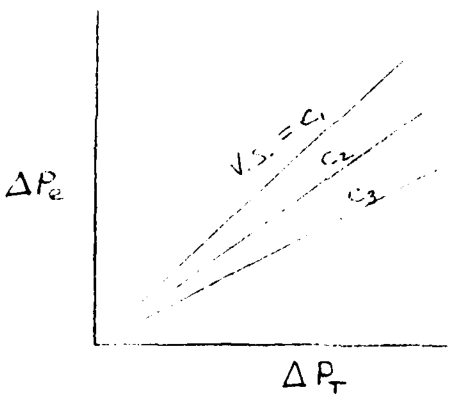


FIGURE A12 DEFINITIONS FOR ANALYSIS OF PITOT LEAK FLIGHT TEST DATA

Fairings are linear regressions

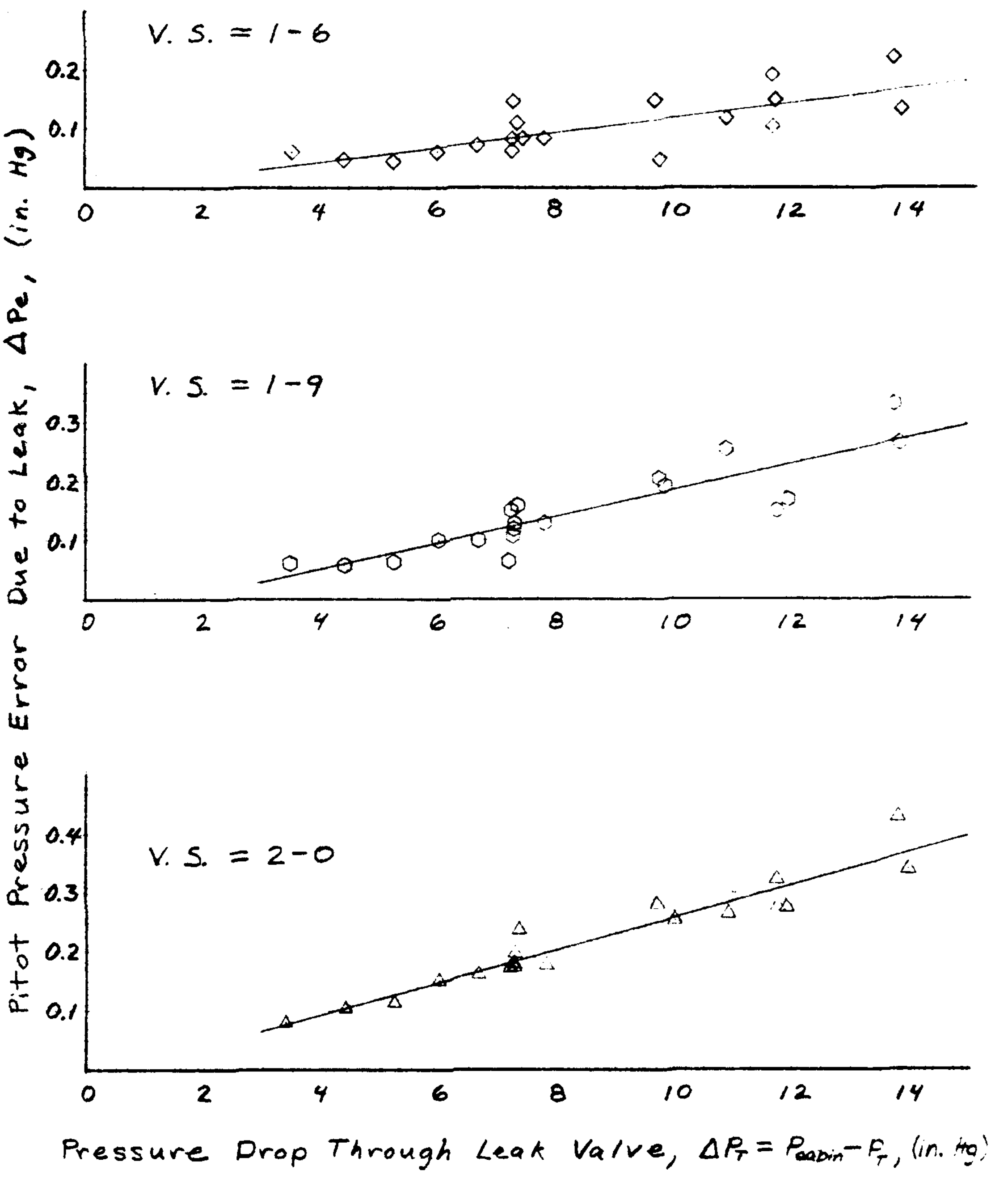
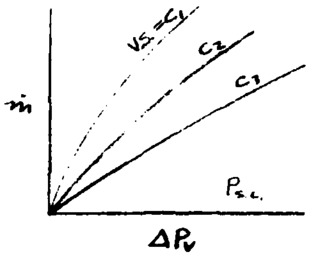
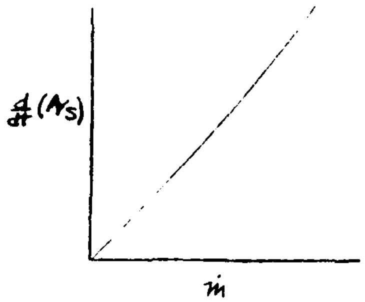


FIGURE A13 FLIGHT TEST DATA FOR PITOT LEAKS

GROUND DATA

Conditions:
Leak check at $V_c = 300$ knots & P_a
$q_c \doteq 4.5$ in. Hg
q_c = pressure drop across any leak
$q_c \equiv \Delta P_v$
Assume test altitude;
$h_1 = 0$ $h_2 = 5{,}000$ ft
Enter ground data plots:



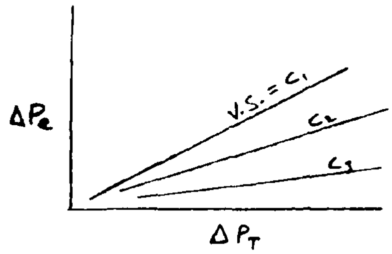


$\frac{d}{dt}(A/s)$

V.S. ↓	h_{Test} →	

FLIGHT DATA

Choose ΔP_c & V_c
$\Delta P_c = 10 - 16$ in. Hg
$V_c = 200, 300, 400$ kts
$q_c = f(V_c)$
$\Delta P_T = f(\Delta P_c, q_c)$
Enter flight data plot:
$\Delta P_e = f(\Delta P_T, V.S.)$

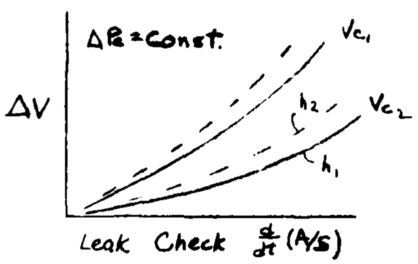


Compute ΔV:
$\Delta V = f(q_c, \Delta P_e)$
$\Delta V = f(V_c, \Delta P_c, V.S.)$

ΔV at V_c = const

V.S. ↓	ΔP_e →					

COMBINE



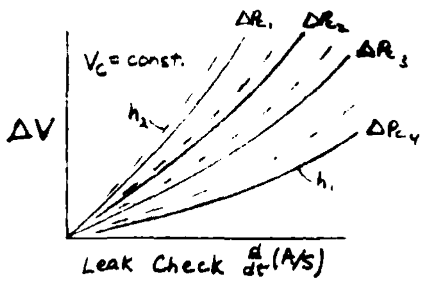


FIGURE A14 DATA CORRELATION FOR PITOT LEAK TEST

APPENDIX B

TEST DATA

NOTES: Symbols represent average of ten readings.
Bars on symbols show max. and min. readings.
Fairings are linear regressions through average values.

Uncertainty of each reading

symbol	valve setting
○	1-6
□	1-9
▽	2-0

H = 30,000 ft
ΔP_c = 9.77 in. Hg
Valve No. 1
Altimeter No. 1

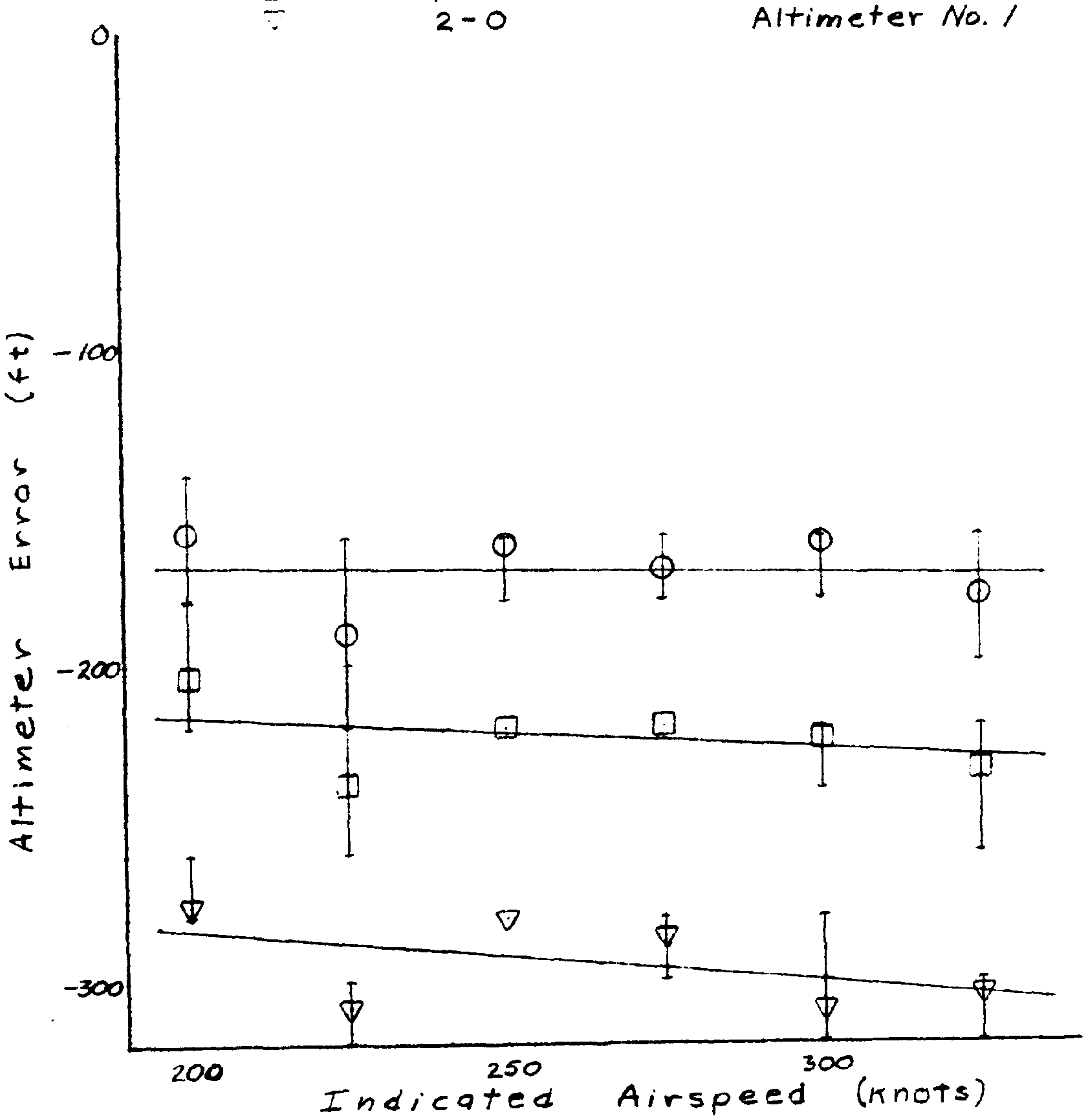


FIGURE B1 ALTIMETER ERROR DEPENDENCE ON AIRSPEED

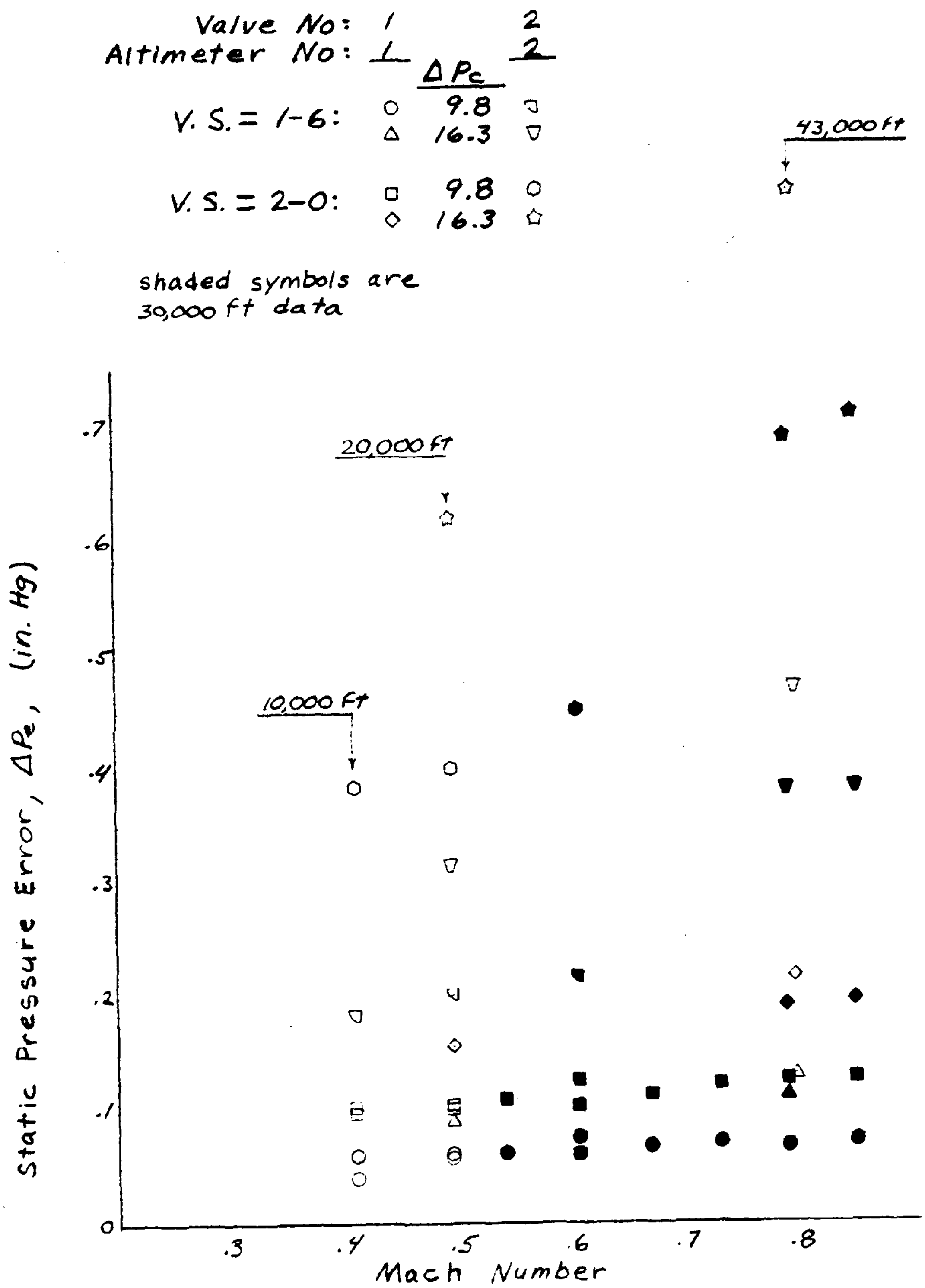


FIGURE B2 MACH NUMBER EFFECT ON STATIC PRESSURE ERROR

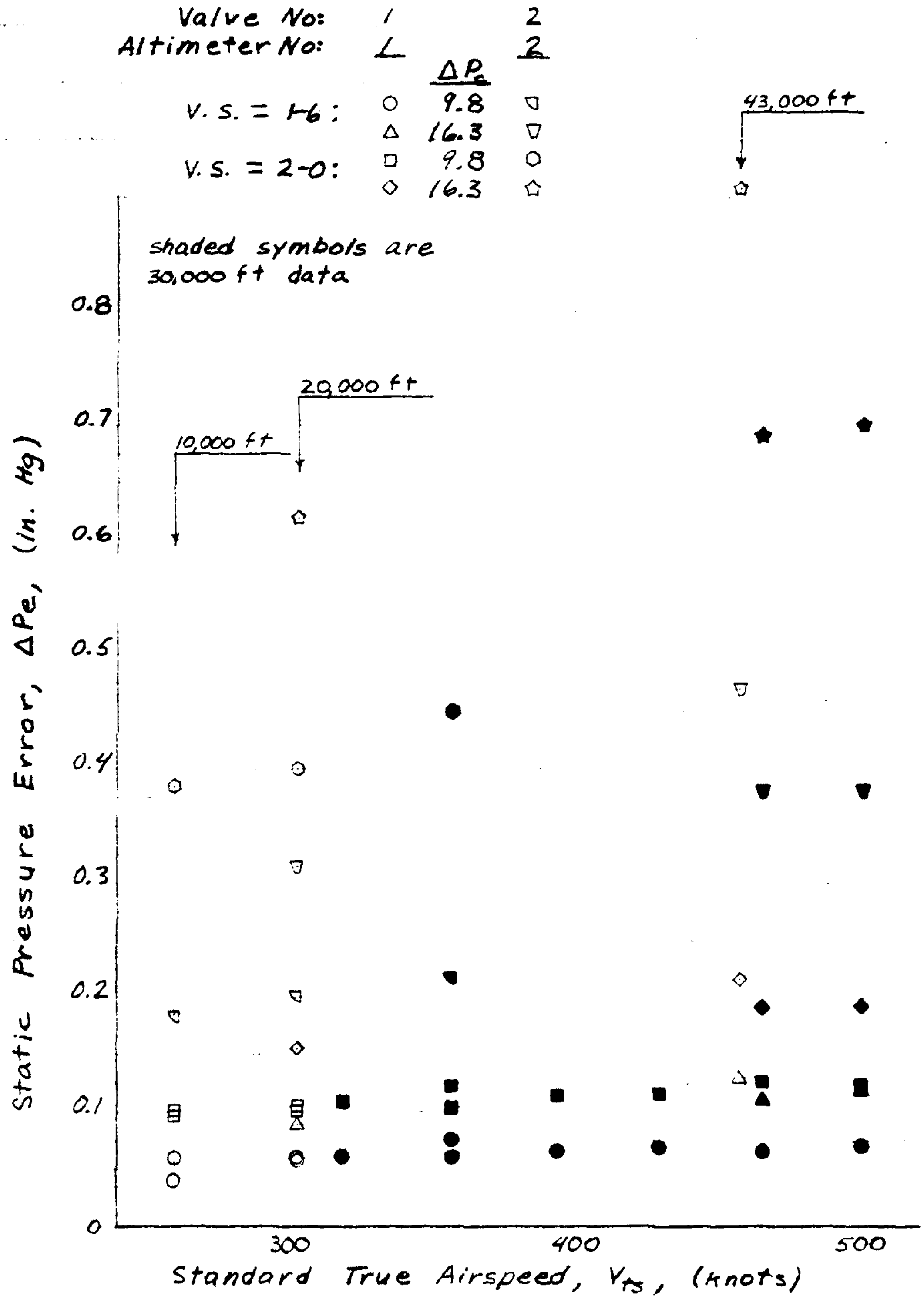


FIGURE B3 TRUE AIRSPEED EFFECT ON STATIC PRESSURE ERROR

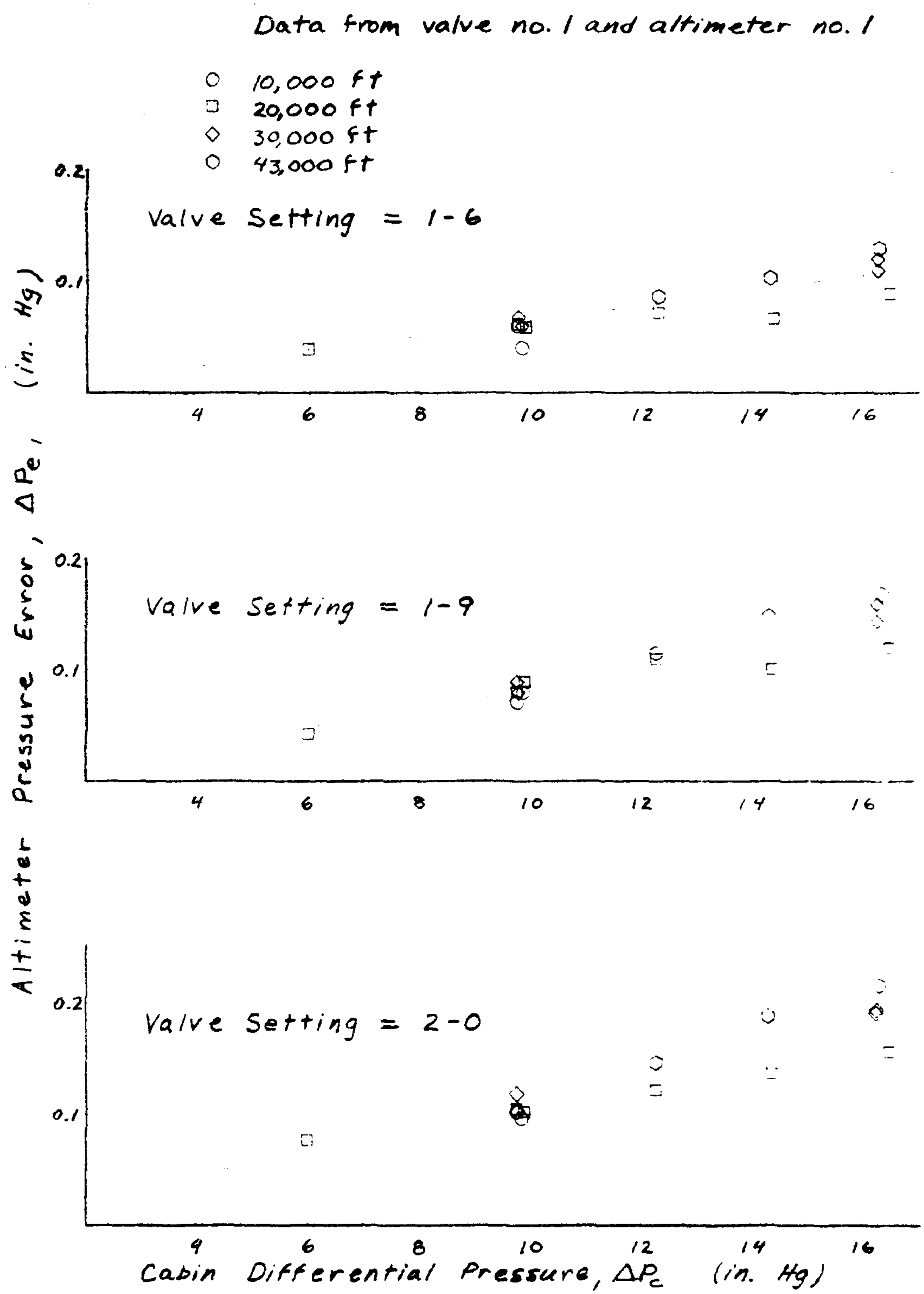


FIGURE B4 PRESSURE ERROR vs CABIN DIFFERENTIAL PRESSURE FOR THREE LEAK VALVE SETTINGS

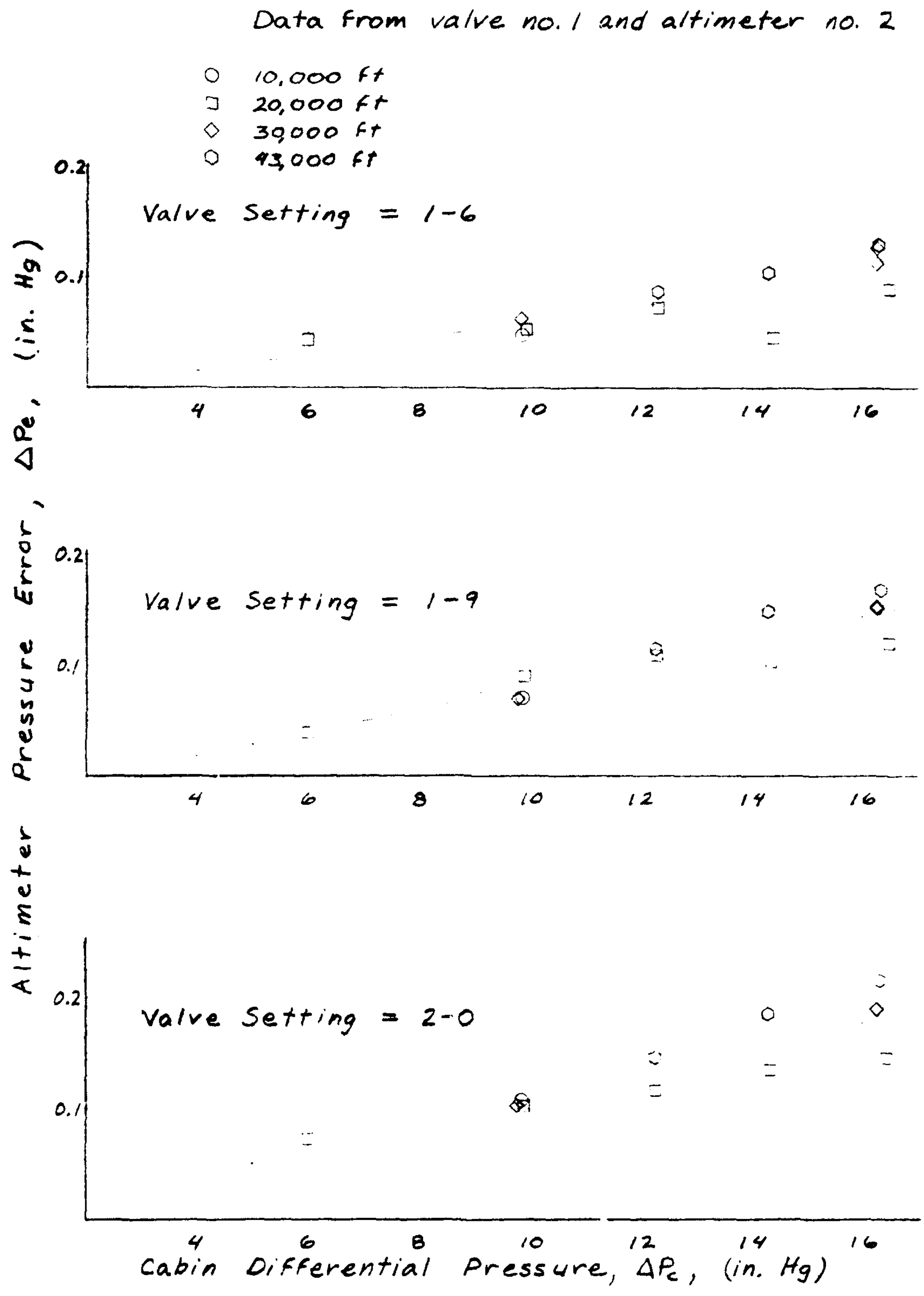


FIGURE B5 PRESSURE ERROR vs CABIN DIFFERENTIAL PRESSURE FOR THREE LEAK VALVE SETTINGS

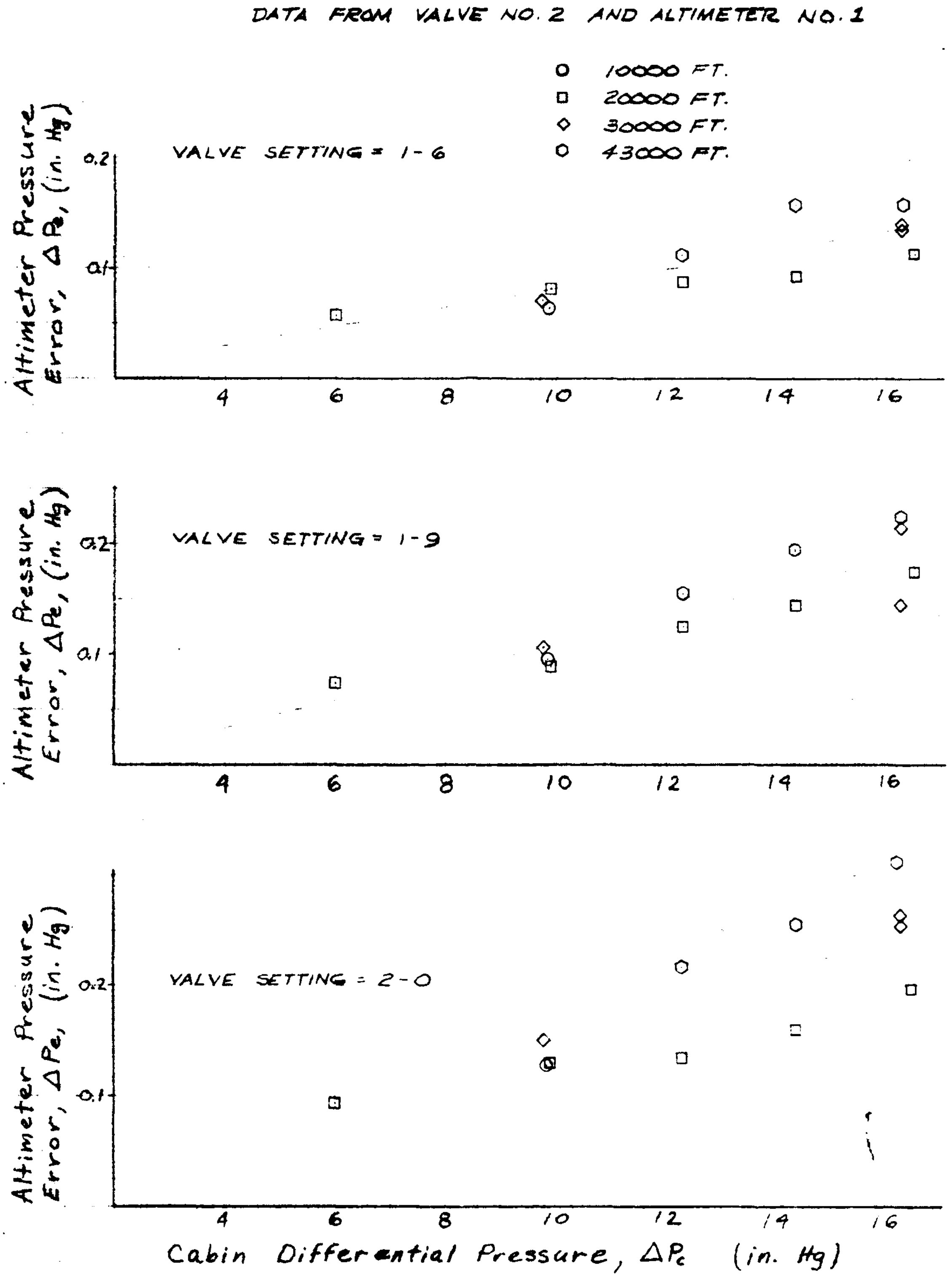


FIGURE B6 PRESSURE ERROR vs CABIN DIFFERENTIAL PRESSURE FOR THREE LEAK VALVE SETTINGS

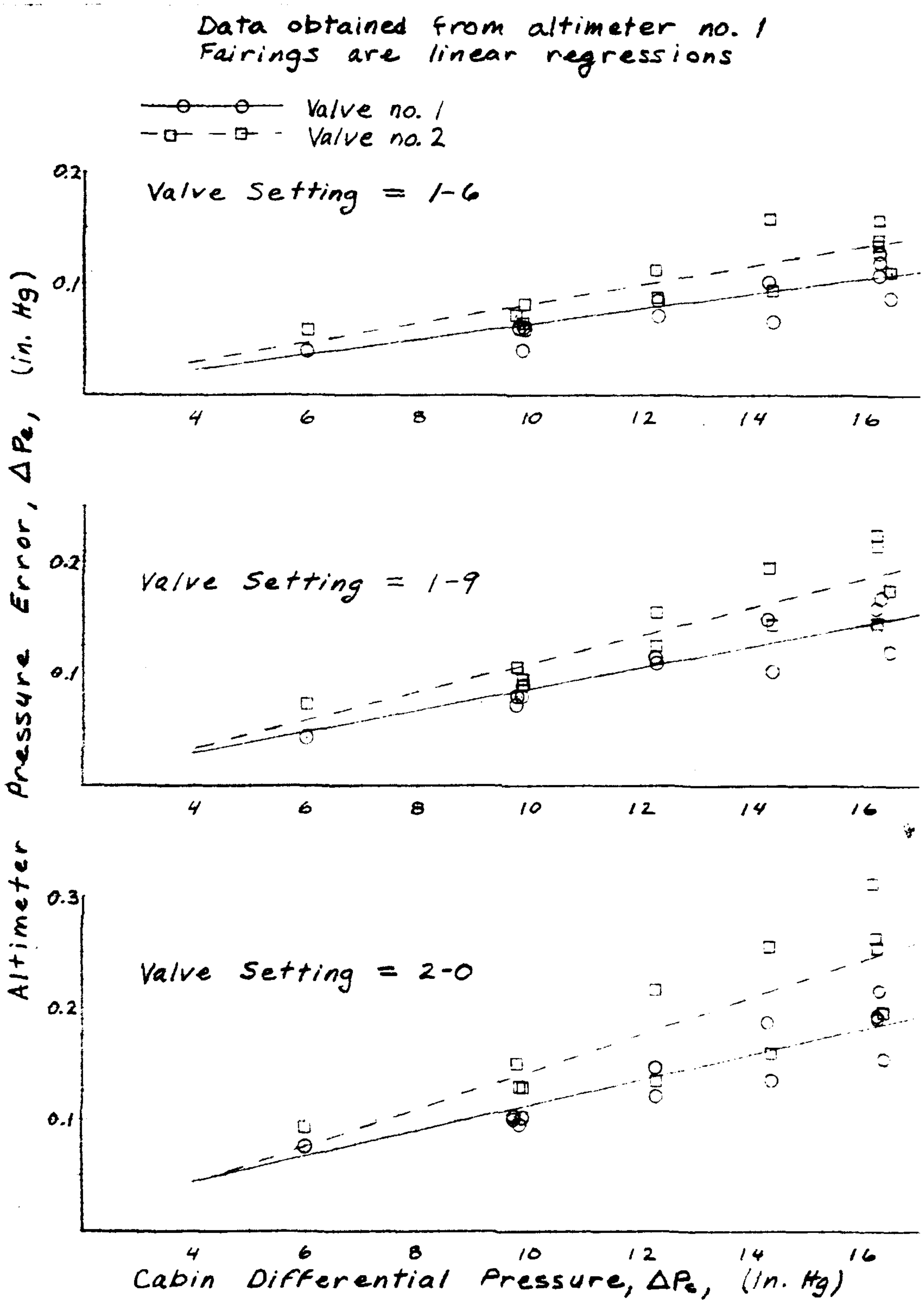


FIGURE B7 PRESSURE ERROR vs CABIN DIFFERENTIAL PRESSURE FOR THREE LEAK VALVE SETTINGS

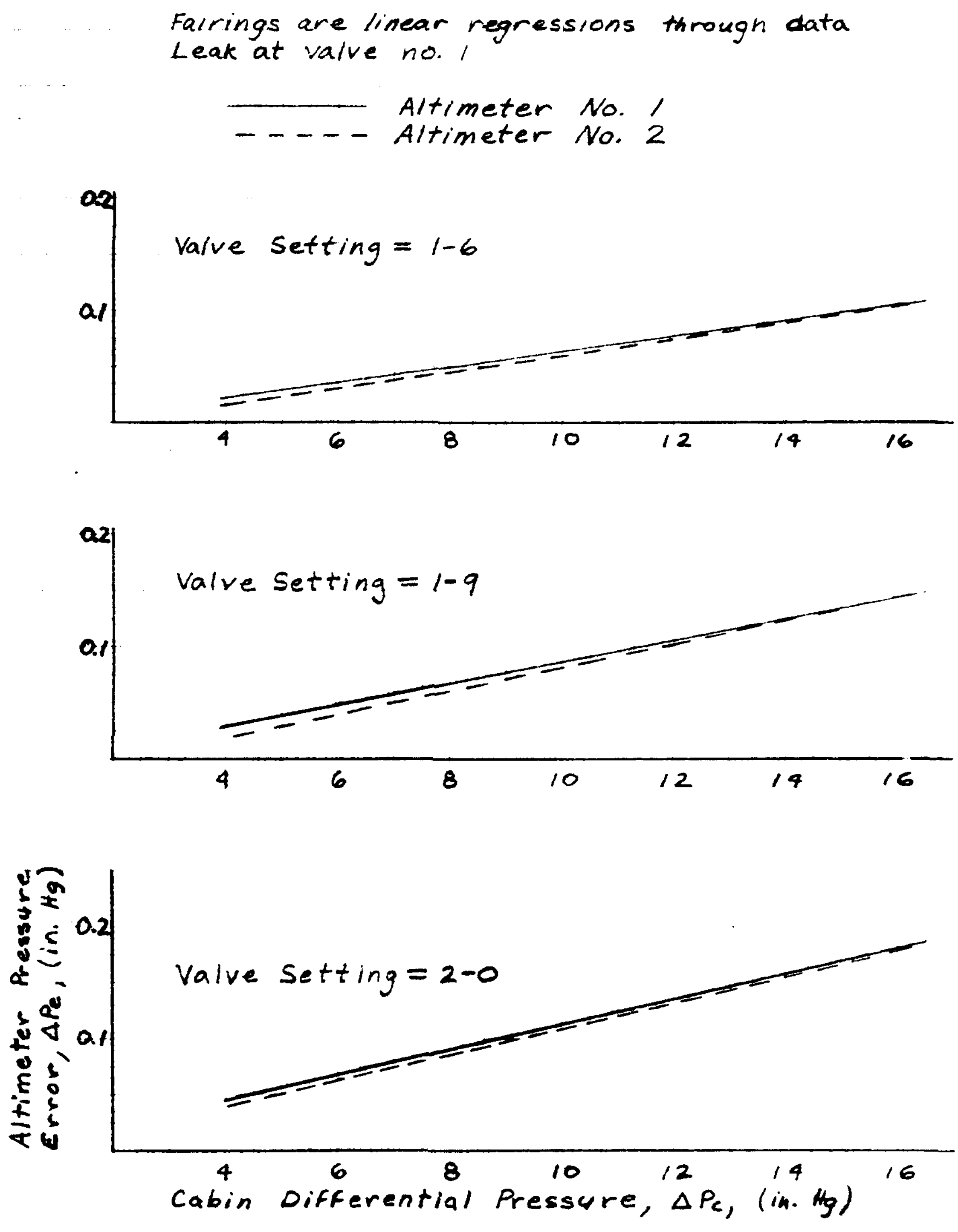


FIGURE B8 COMPARISON OF LEAK-INDUCED ERRORS MEASURED AT AND UPSTREAM OF LEAK

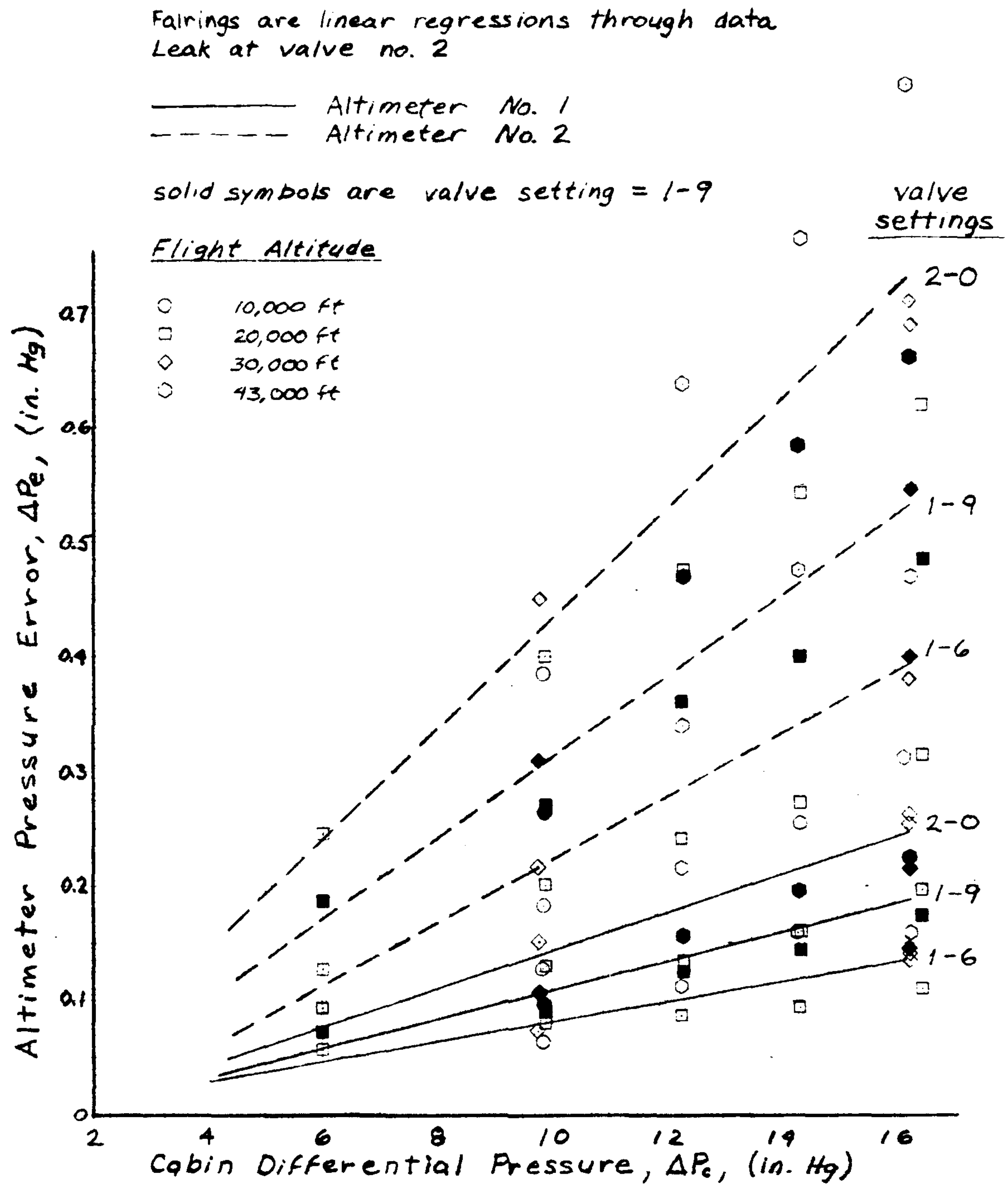


FIGURE B9 COMPARISON OF LEAK-INDUCED ERRORS MEASURED AT AND DOWNSTREAM OF LEAK

Note: Apply to KC-135A. Original data from valves no. 1 & 2 and altimeter no. 1. Fairings based on data derived from figures 5 and B7 per Appendix A.

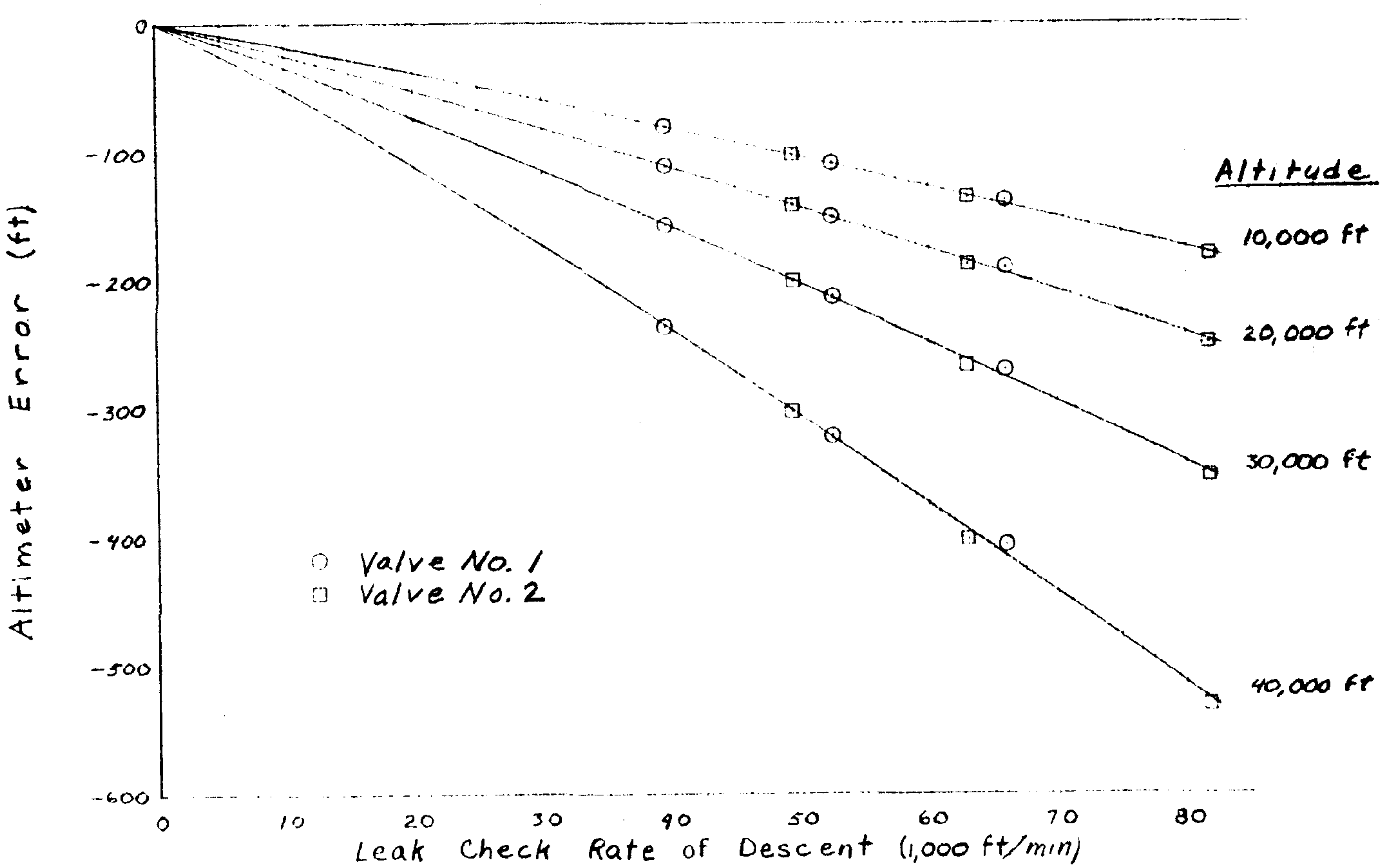


FIGURE B10 EXAMPLE OF DERIVED DATA AND FAIRINGS FOR LEAK ALTIMETER ERRORS, $\Delta P_c = 10$ in. Hg

Note: Apply to KC-135A. Original data from valves no. 1 & 2 and altimeter no. 1. Fairings based on data derived from figures 5 and B7 per Appendix A.

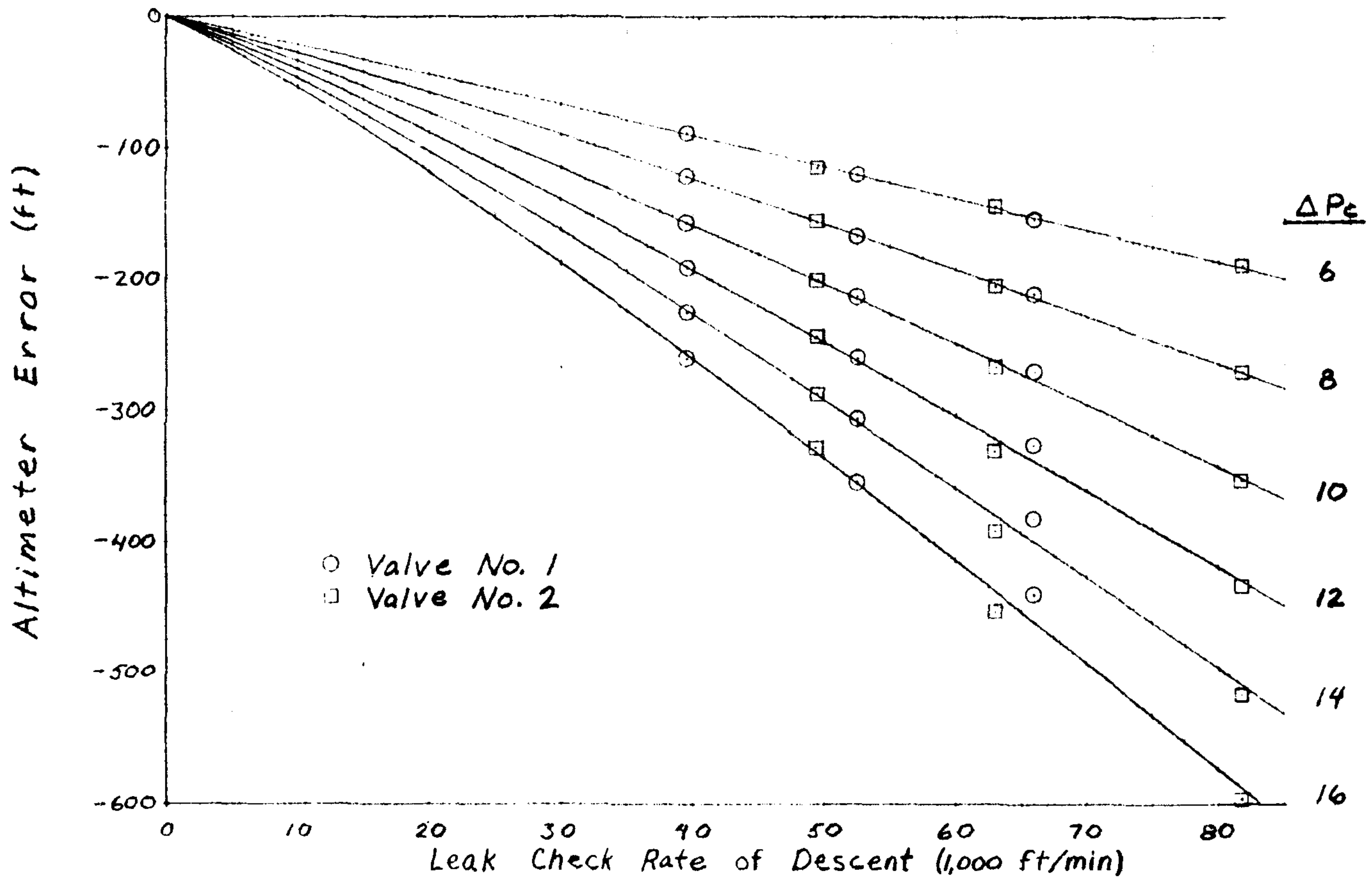


FIGURE B11 EXAMPLE OF DERIVED DATA AND FAIRINGS FOR LEAK ALTIMETER ERRORS, $H_c = 30{,}000$ FT

Note: Original data from valves no. 1 & 2 and altimeter no. 1.
Fairings are based on data derived from figures 5 and B7 per Appendix A.

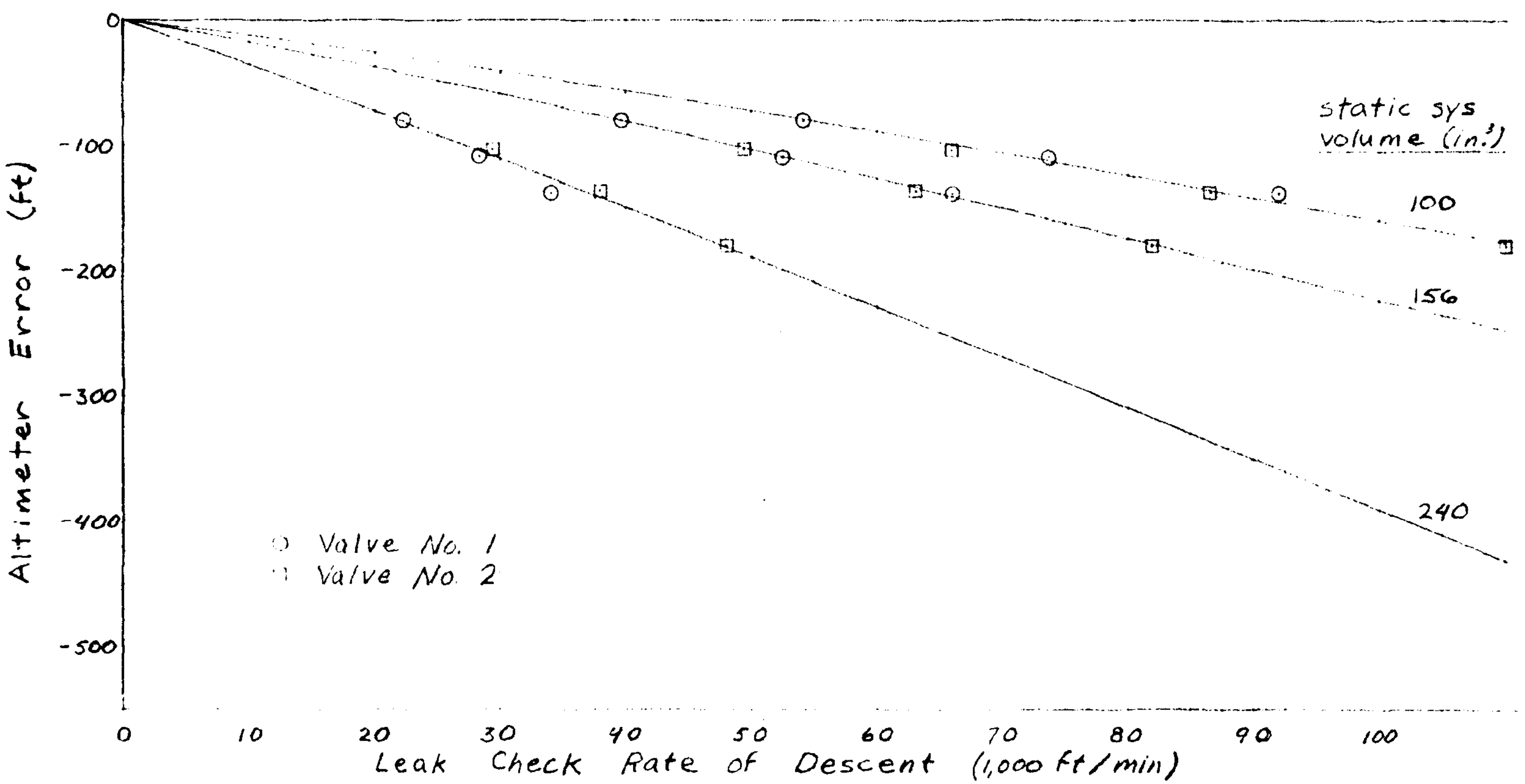


FIGURE B12 EFFECTS OF VOLUME ON LEAK INDUCED ALTIMETER ERRORS,
$\Delta P_c = 10$ in. Hg, $H_c = 10{,}000$ ft

Note: Original data from valve no. 1 & 2 and altimeter no. 1.
Fairings are based on data derived from figures 5 & B7 per Appendix A.

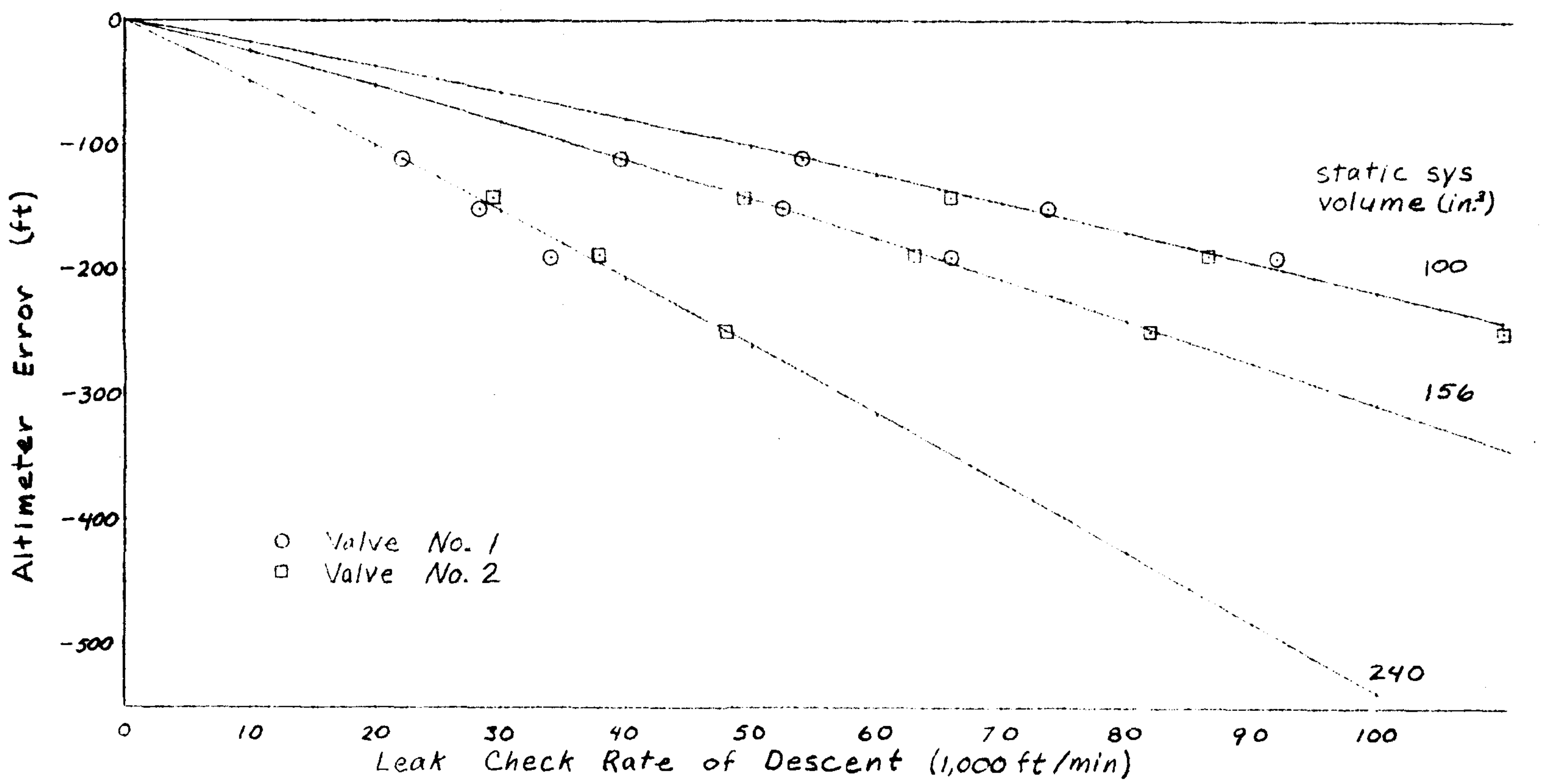


FIGURE B13 EFFECTS OF VOLUME ON LEAK-INDUCED ALTIMETER ERRORS, $\Delta P_c = 10$ in. Hg, $H_c = 20{,}000$ ft

Note: Original data from valve no. 1 & 2 and altimeter no. 1
Fairings are based on data derived from figures 5 & B7 per Appendix A.

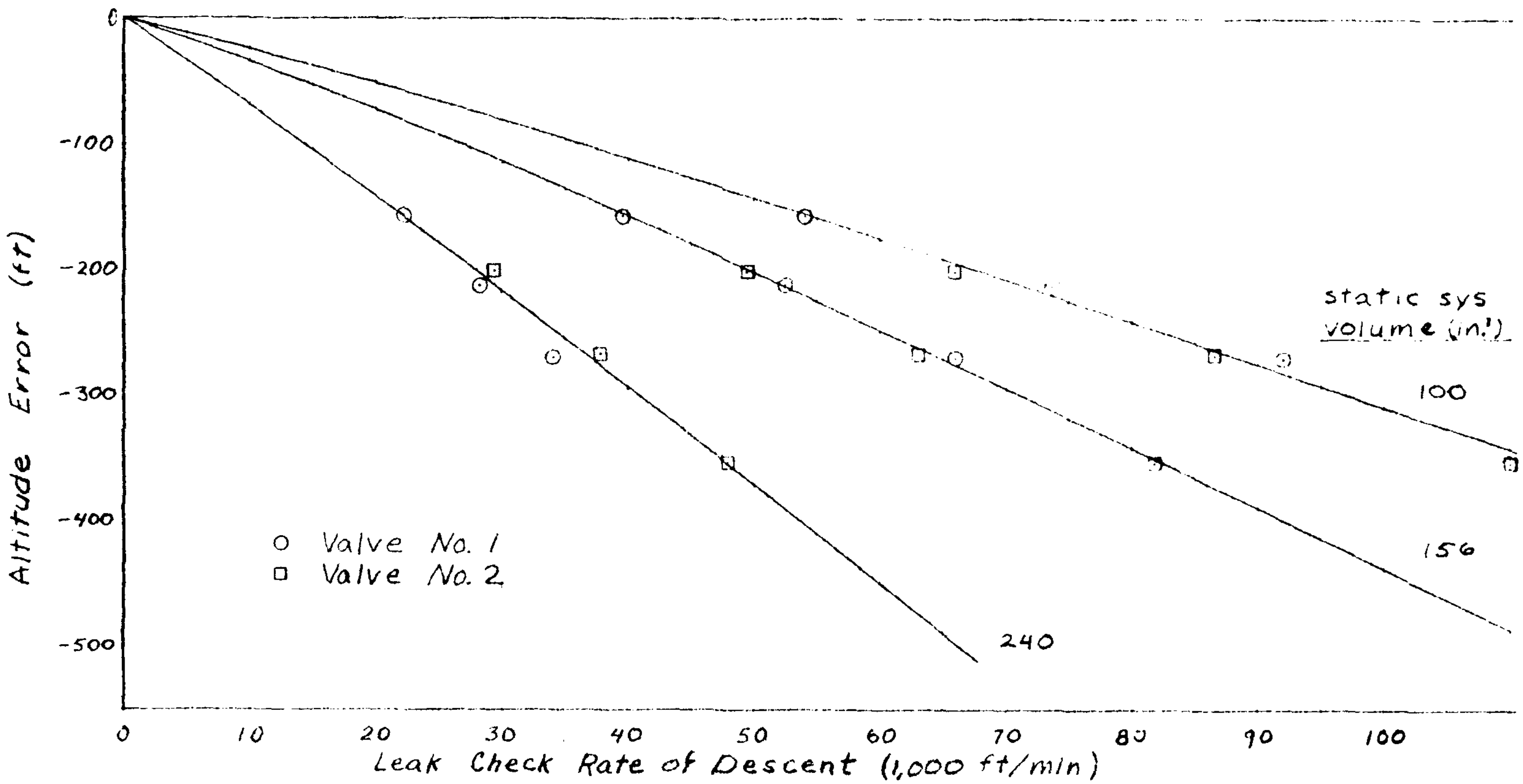


FIGURE B14 EFFECTS OF VOLUME ON LEAK-INDUCED ALTIMETER ERRORS,
$\Delta P_c = 10$ in. Hg, $H_c = 30{,}000$ ft

Note: Original data from valve no. 1 & 2 and altimeter no. 1.
Fairings are based on data derived from figures 5 & B7 per Appendix A.

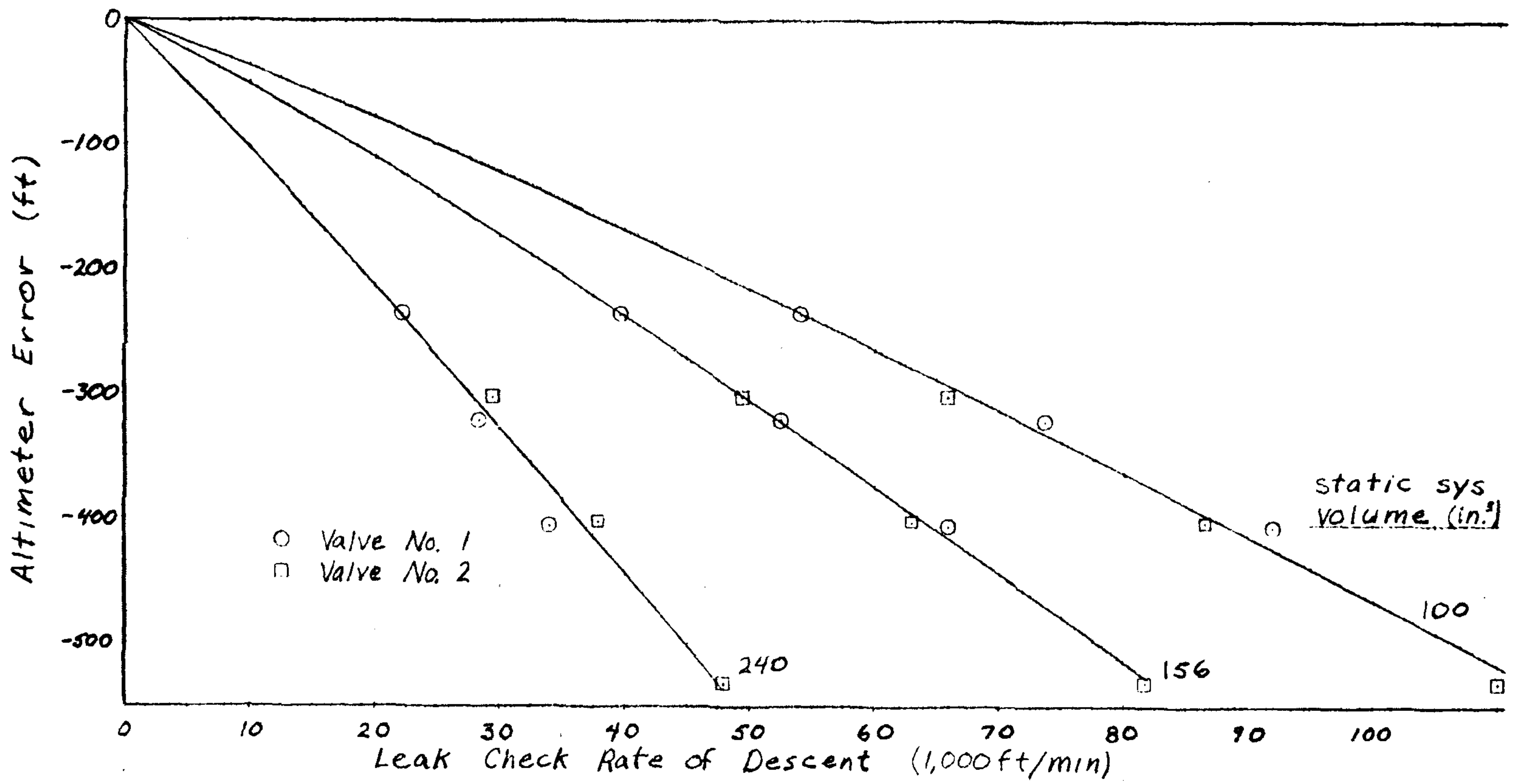


FIGURE B15 EFFECTS OF VOLUME ON LEAK-INDUCED ALTIMETER ERRORS,
$\Delta P_c = 10$ in. Hg, $H_c = 40{,}000$ ft

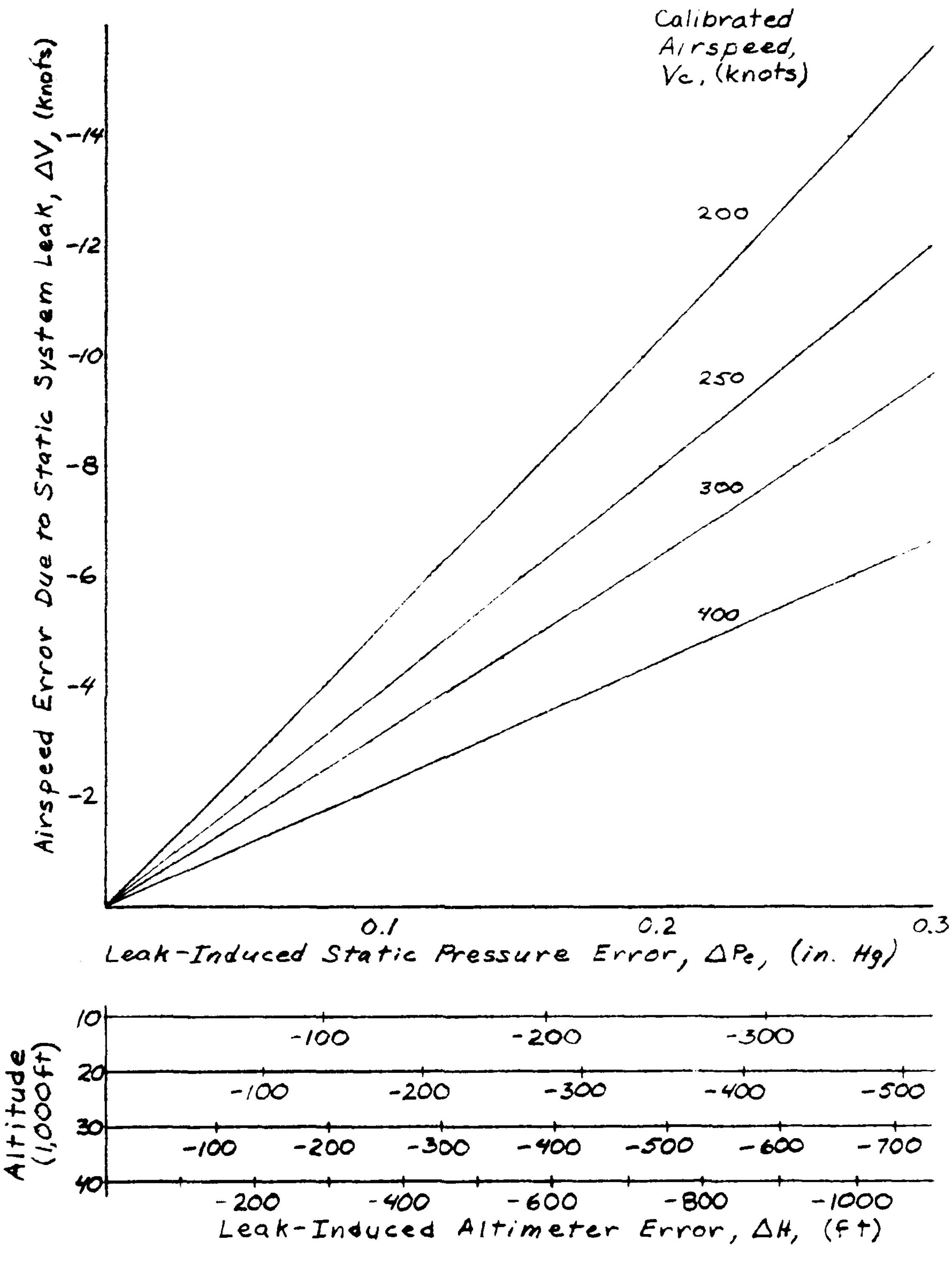


FIGURE B16 AIRSPEED ERRORS DUE TO STATIC LEAKS

APPENDIX C

TEST RESULTS FOR TEST AIRCRAFT

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A

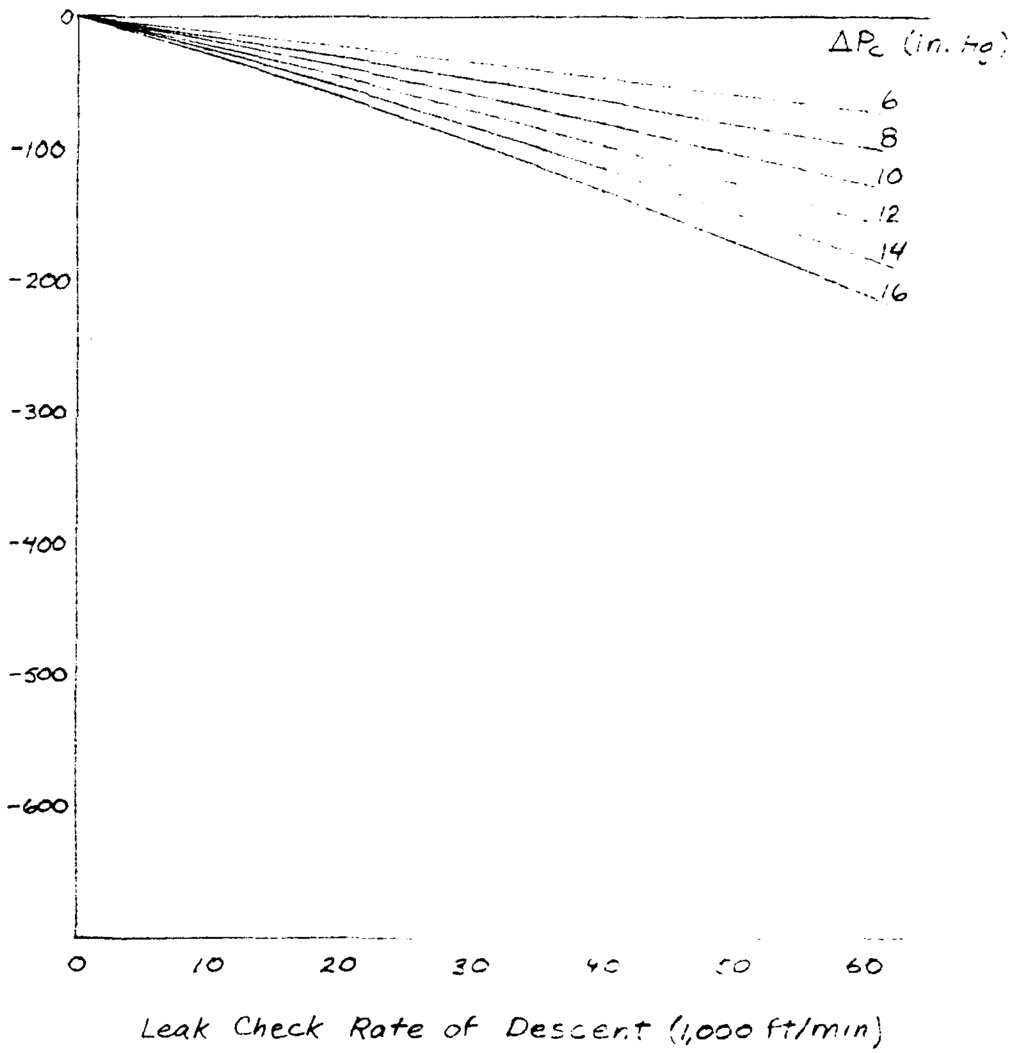


FIGURE C1 EFFECT OF LEAK ON ALTIMETER, $H_c = 10{,}000$ ft

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A

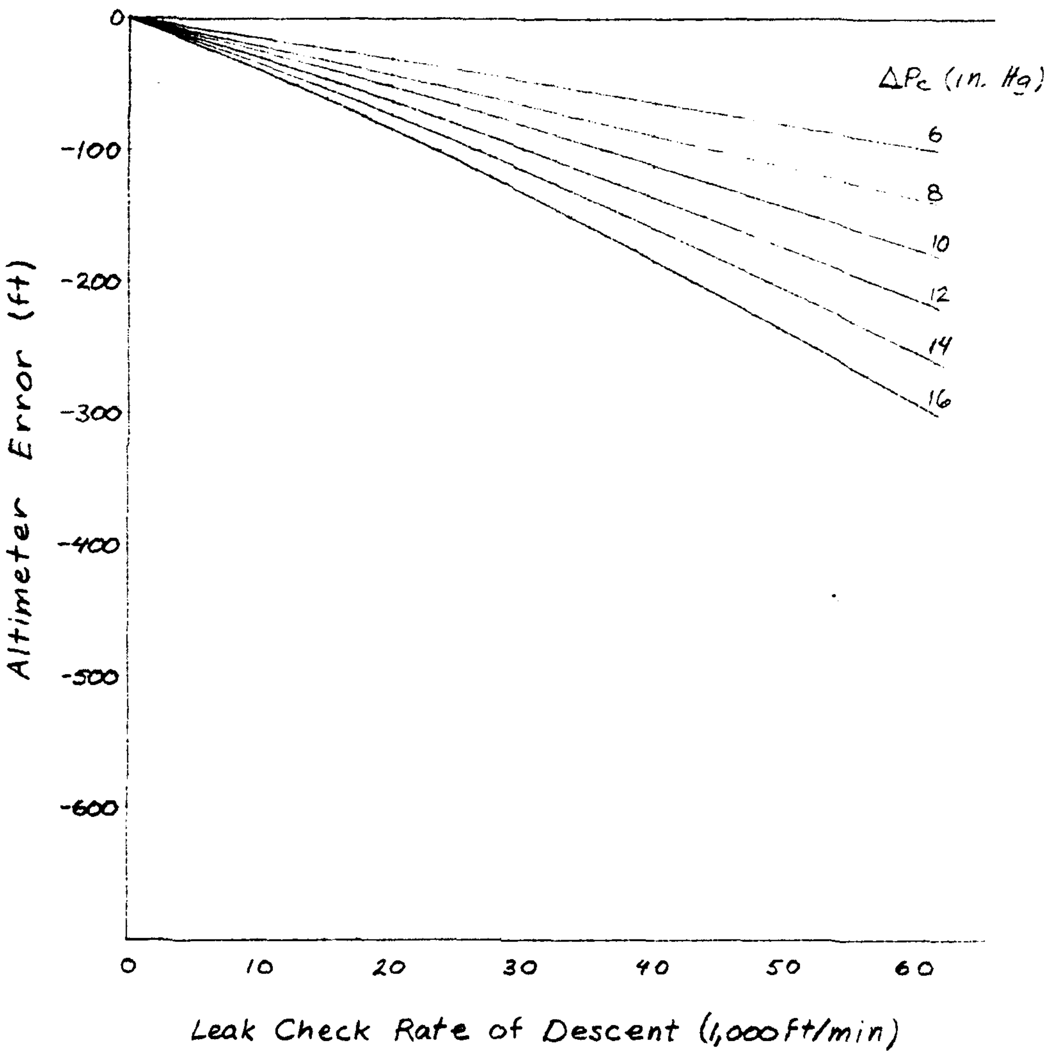


FIGURE C2 EFFECT OF LEAK ON ALTIMETER, H_c = 20,000 ft

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

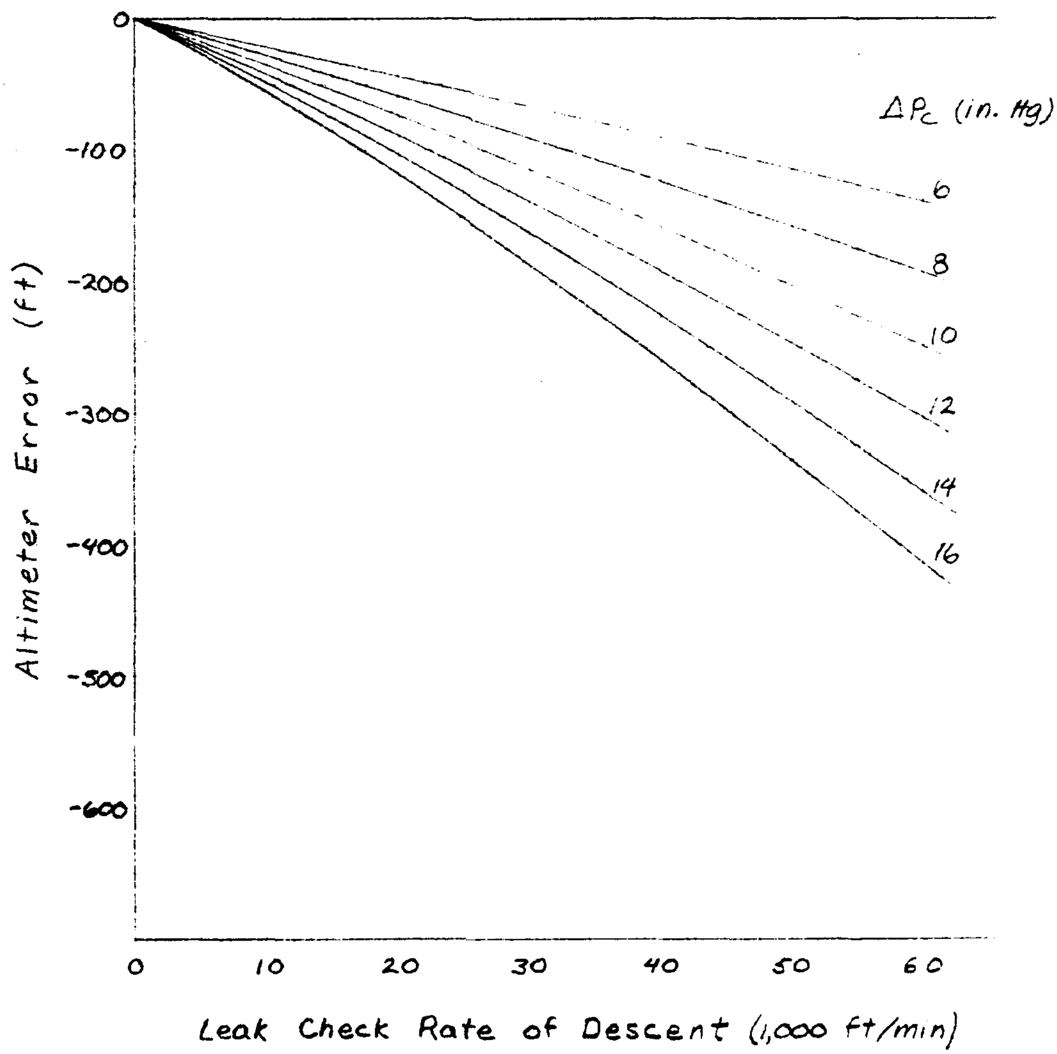


FIGURE C3 EFFECT OF LEAK ON ALTIMETER, H_c = 30,000 ft

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

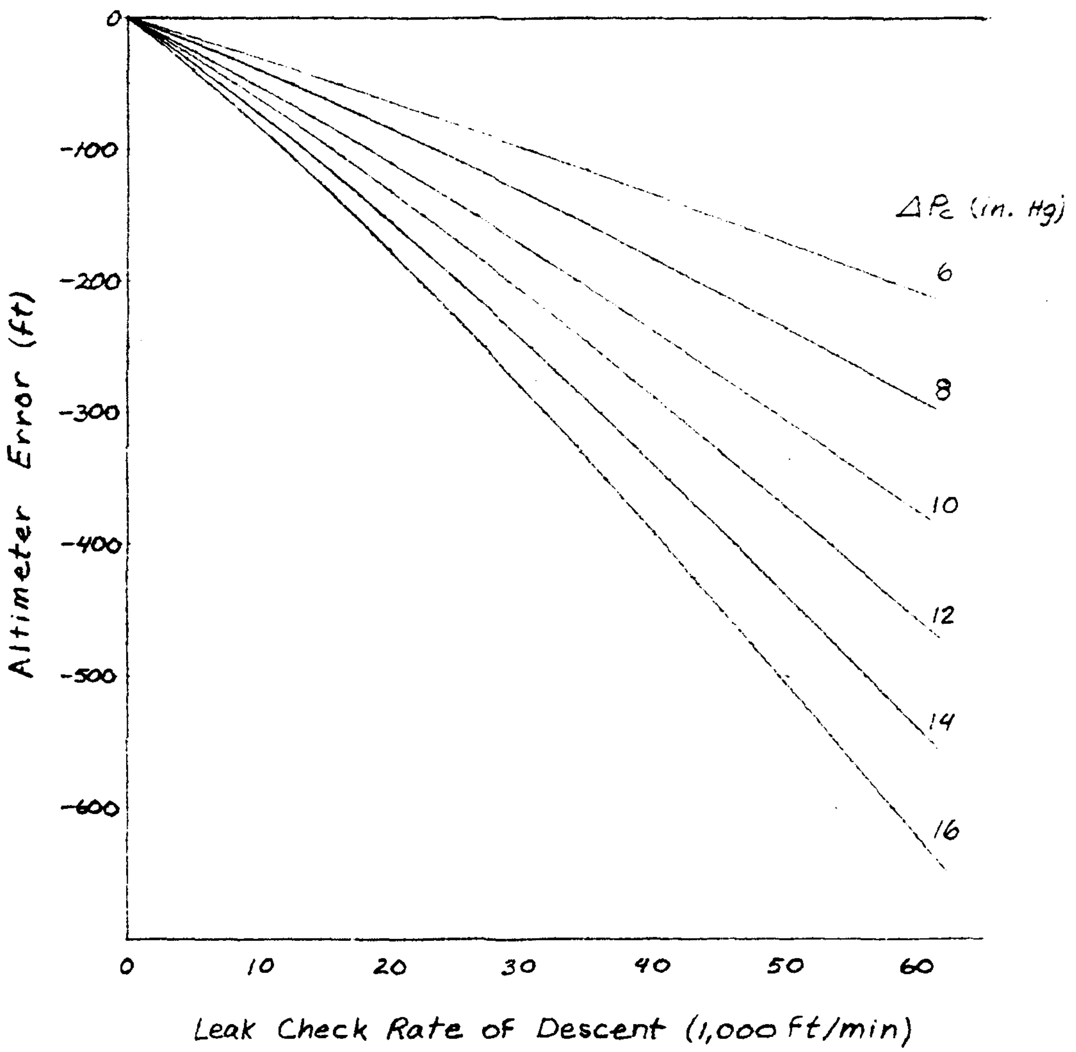


FIGURE C4 EFFECT OF LEAK ON ALTIMETER, H_c = 40,000 ft

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A

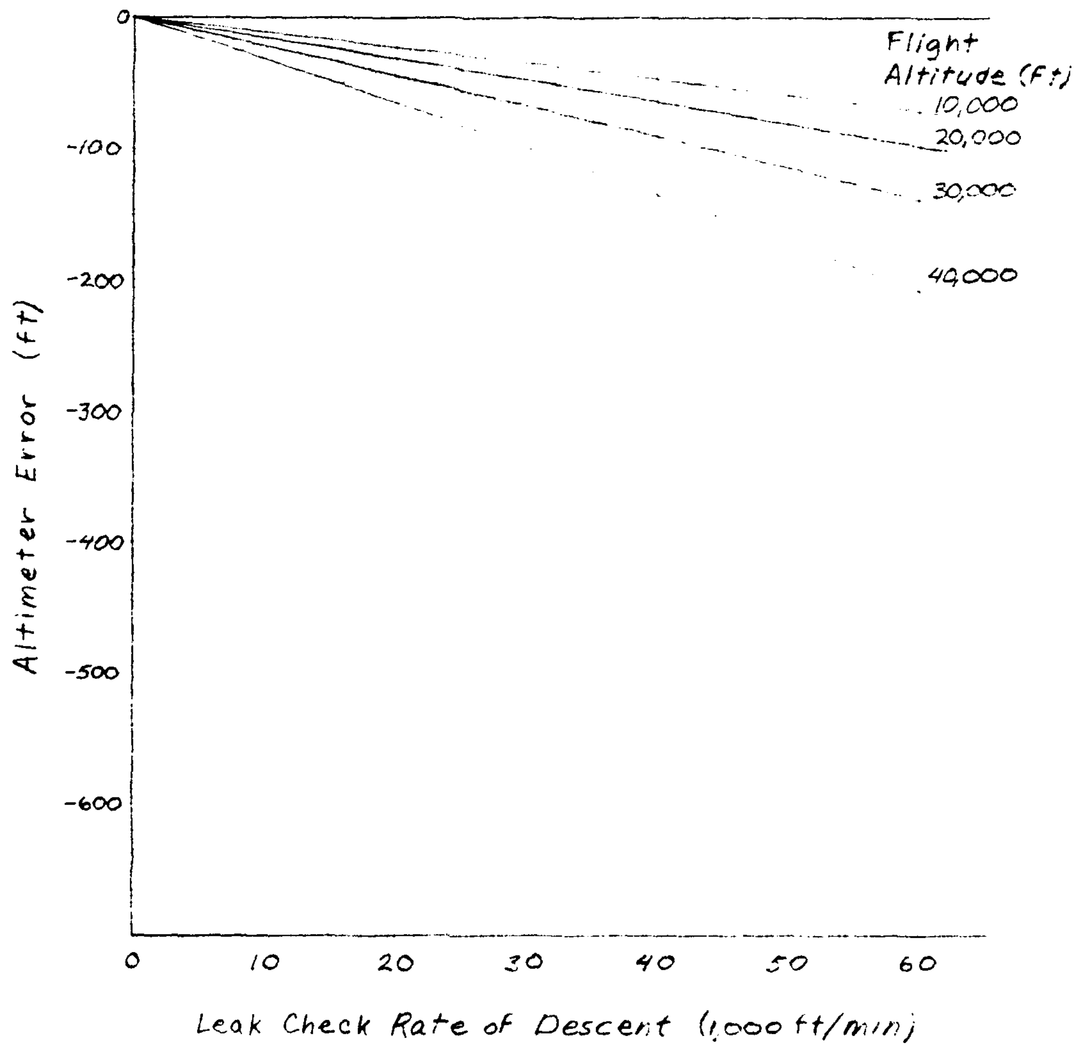


FIGURE C5 EFFECT OF LEAK ON ALTIMETER, $\Delta P_c = 6$ in. Hg

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

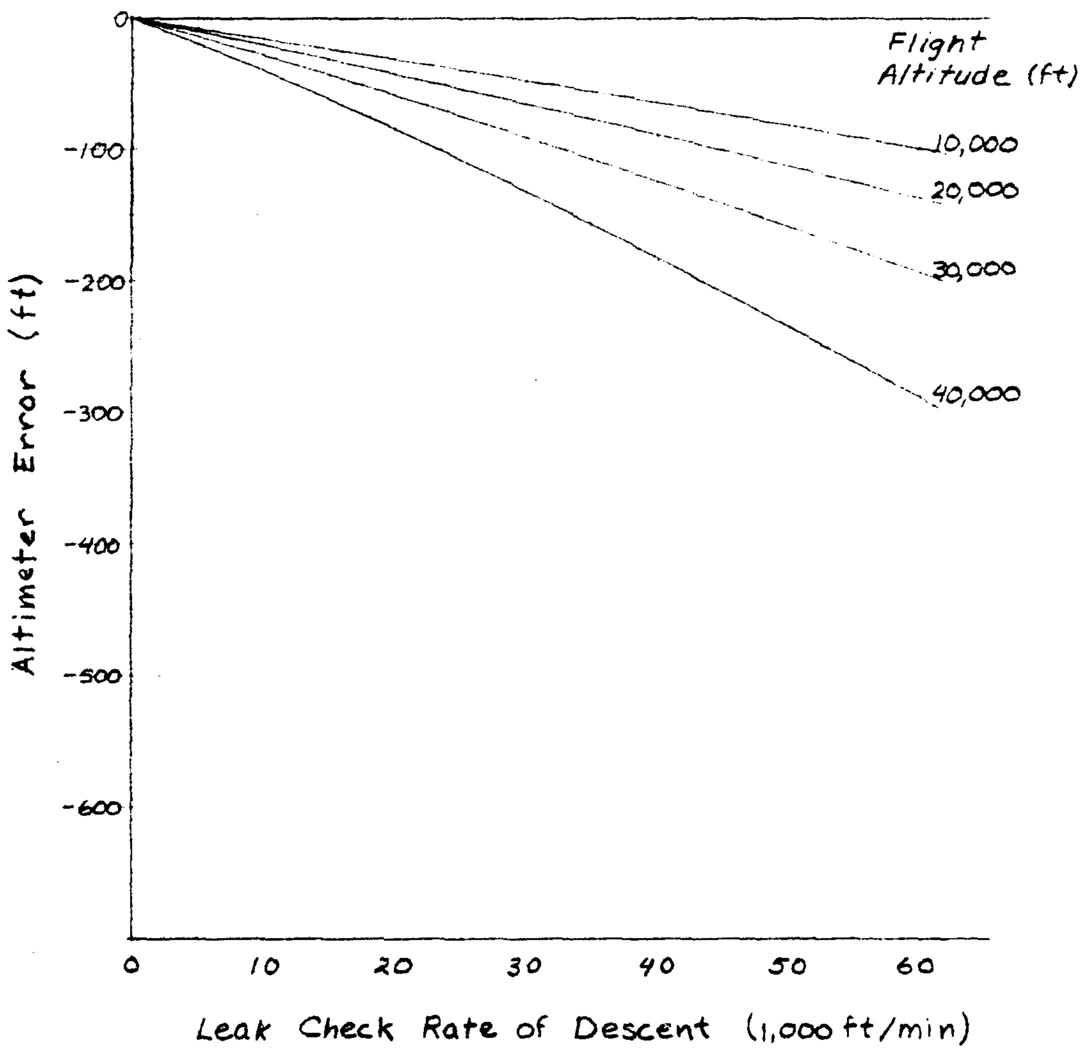


FIGURE C6 EFFECT OF LEAK ON ALTIMETER, ΔP_c = 8 in. Hg

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

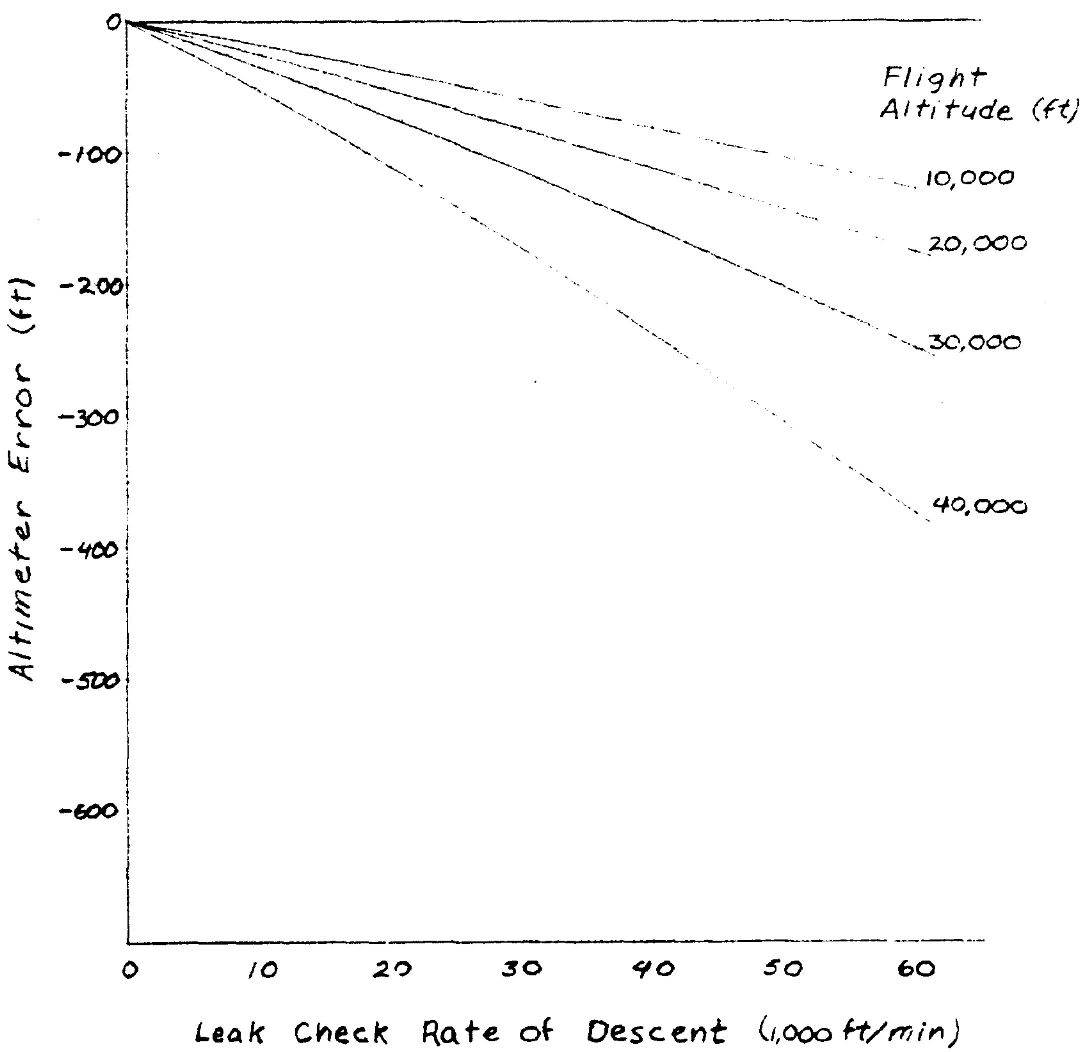


FIGURE C7 EFFECT OF LEAK ON ALTIMETER, ΔP_c = 10 in. Hg

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

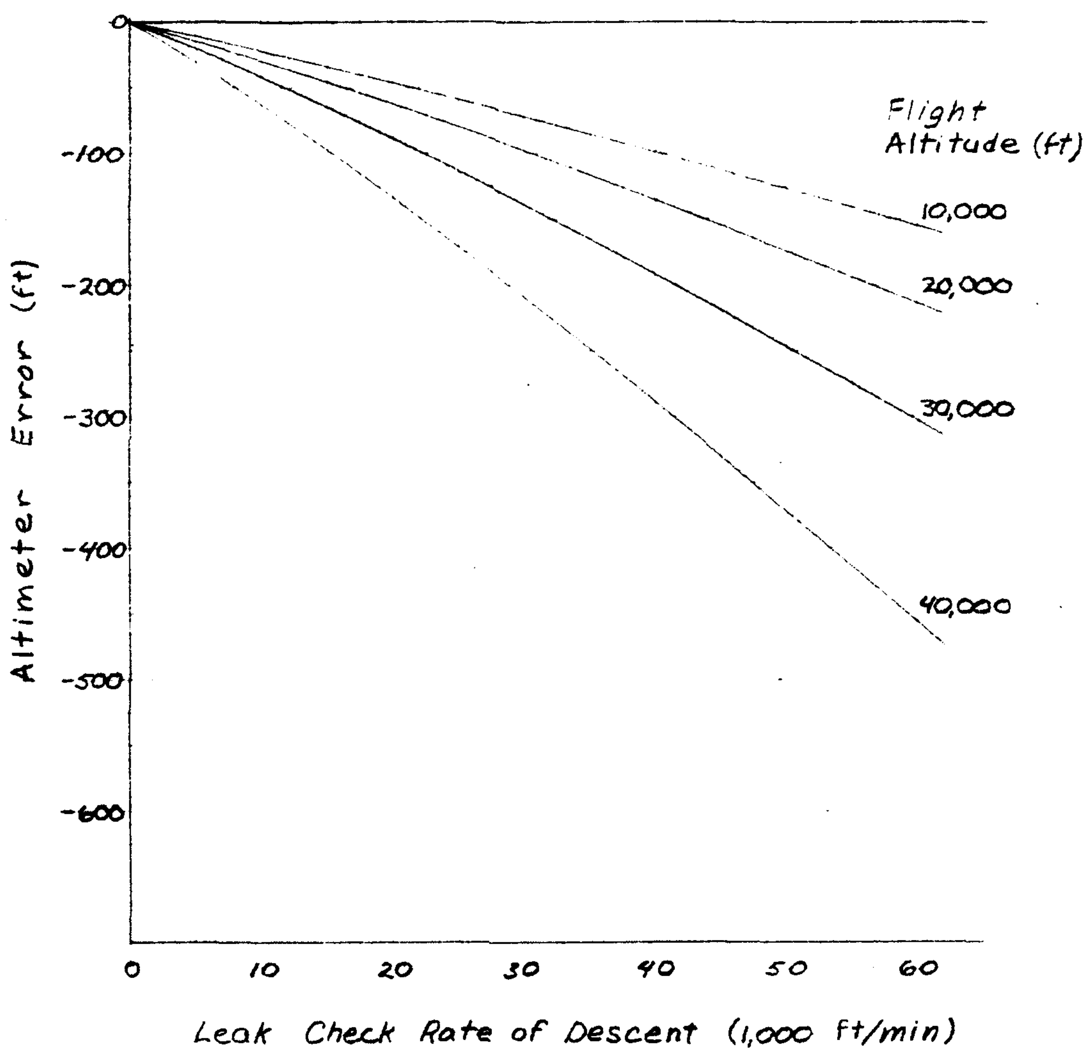


FIGURE C8 EFFECT OF LEAK ON ALTIMETER, $\Delta P_c = 12$ in. Hg.

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1

Fairings based on data derived from figures 5 and B7 per Appendix A.

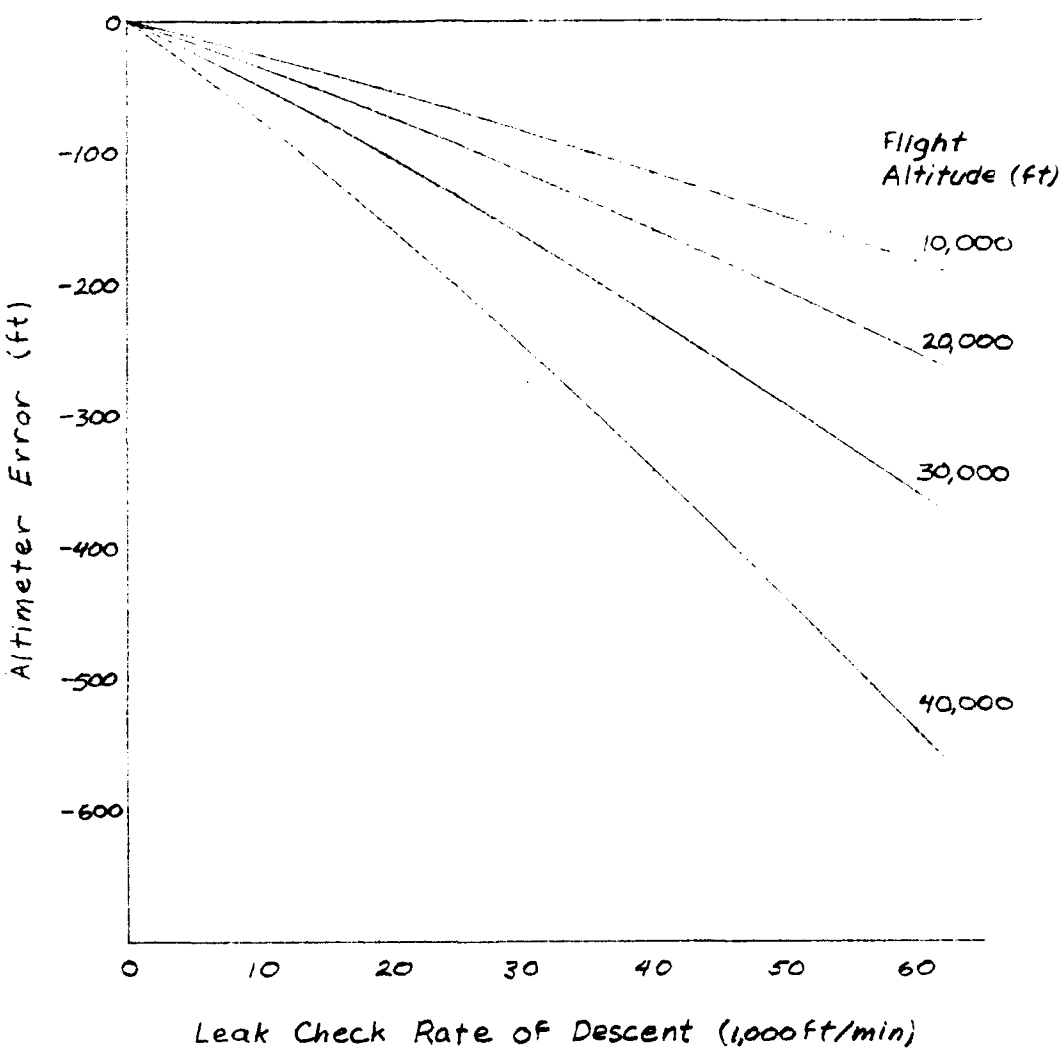


FIGURE C9 EFFECT OF LEAK ON ALTIMETER, $\Delta P_c = 14$ in. Hg

Note: Apply to KC-135A

Original data from valves no. 1 & 2 and altimeter no. 1.

Fairings based on data derived from figures 5 and 87 per Appendix A.

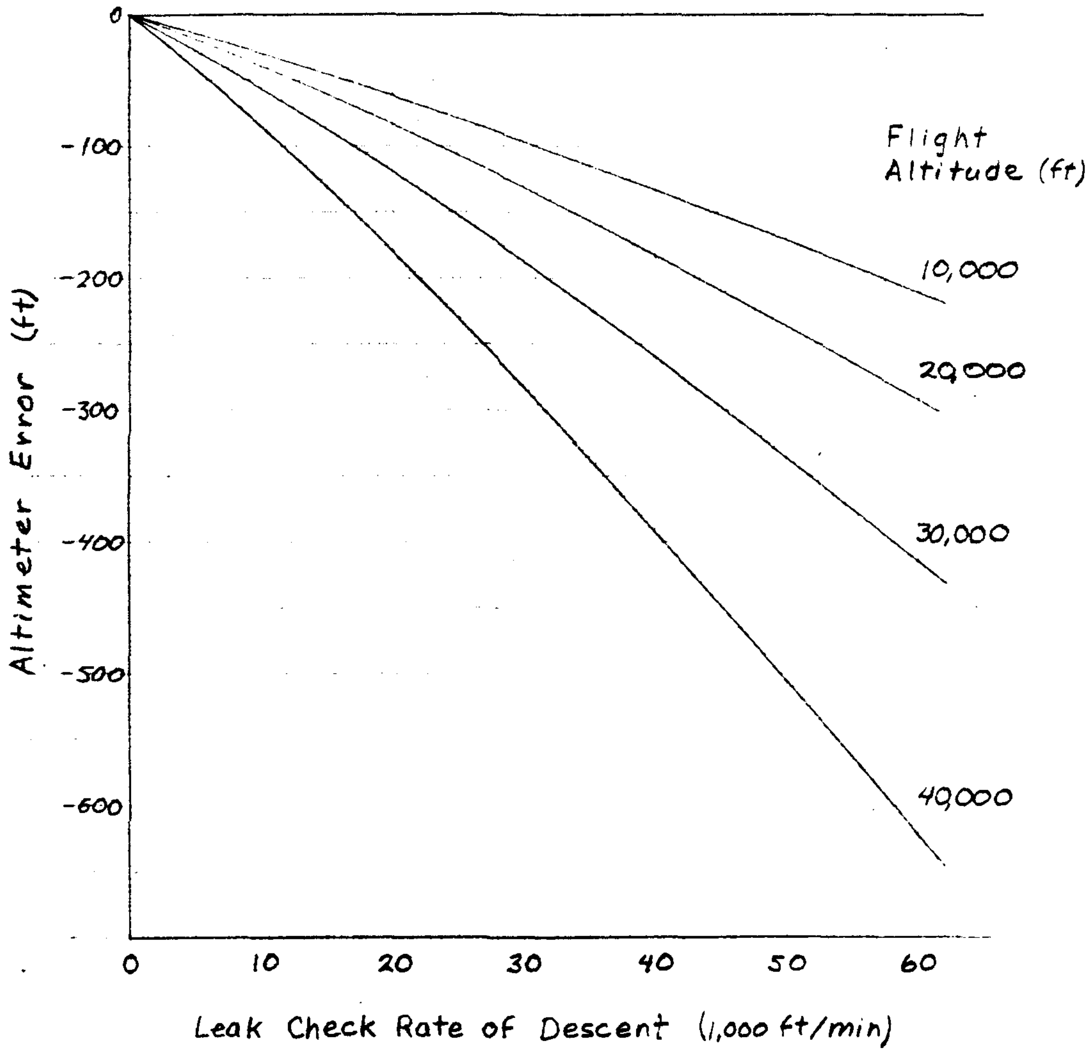


FIGURE C10 EFFECT OF LEAK ON ALTIMETER, $\Delta P_c = 16$ in. Hg

Note: Apply to KC-135A.
Perform leak check at 300 knots.

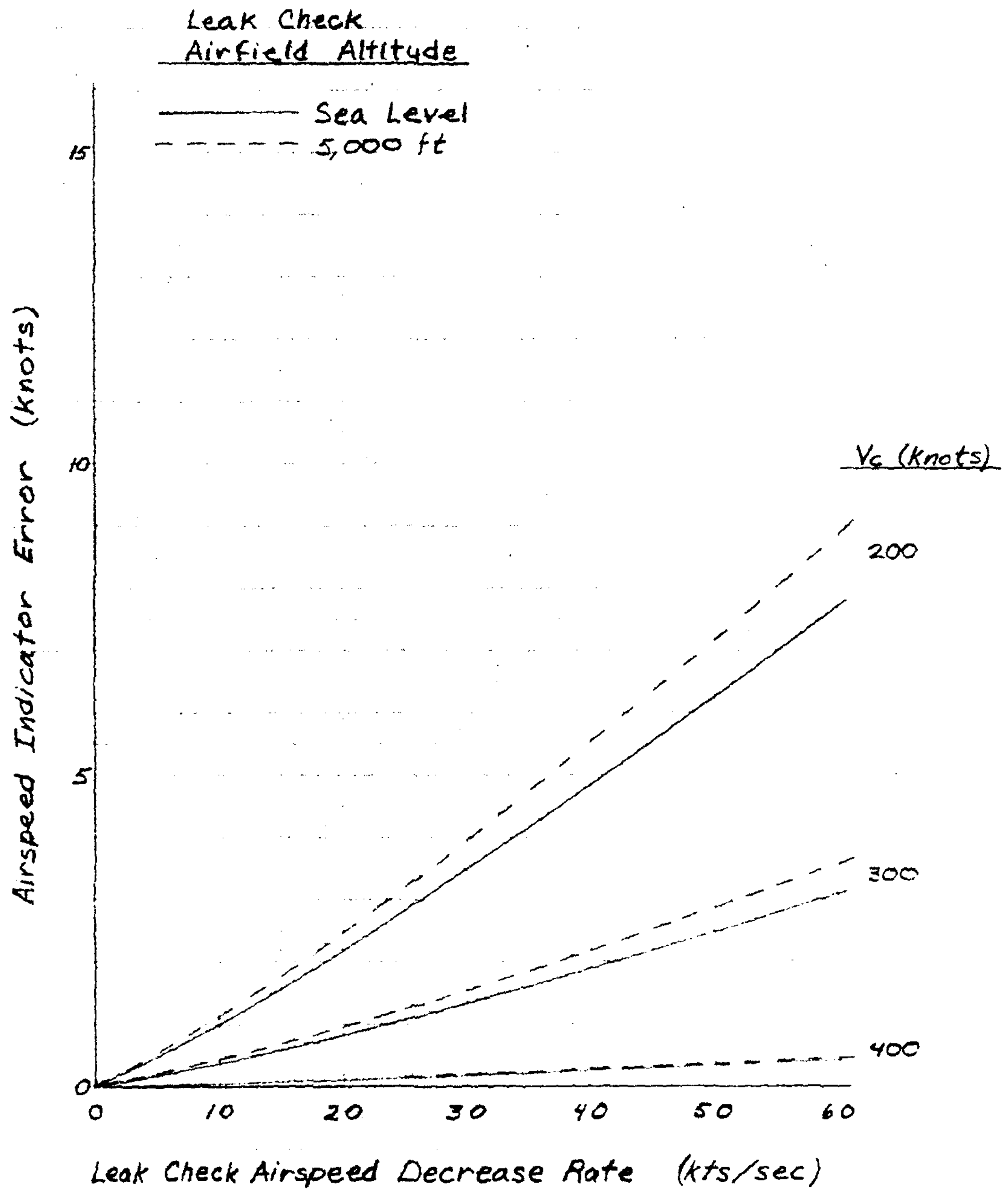


FIGURE C11 PITOT LEAK AIRSPEED ERROR WITH $\Delta P_c = 10$ in. Hg

Note: Apply to KC-135A
Perform leak check at 300 knots.

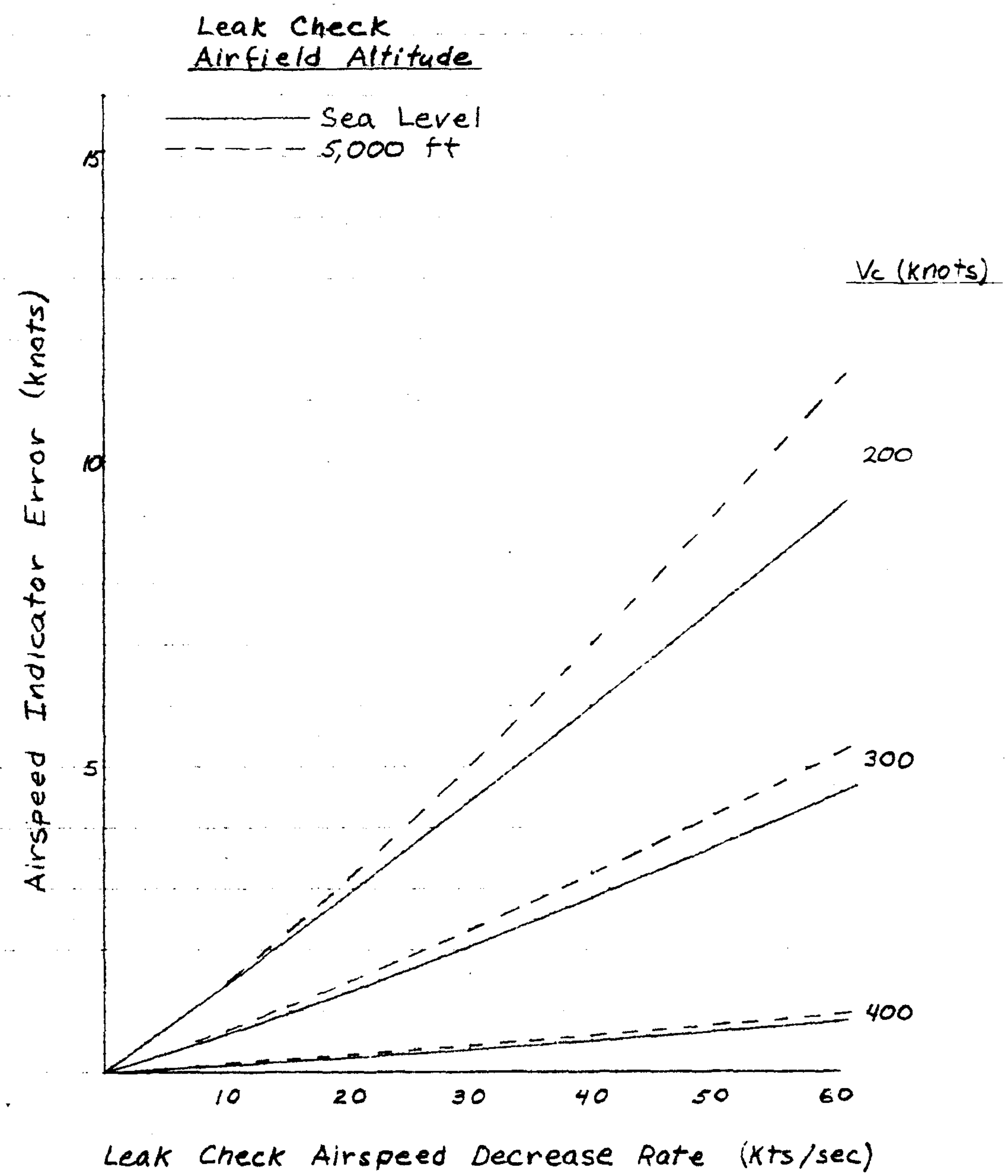


FIGURE C12 PITOT LEAK AIRSPEED ERRORS WITH
$\Delta P_c = 12$ in. Hg

Note: Apply to KC-135A
Perform leak check at 300 knots.

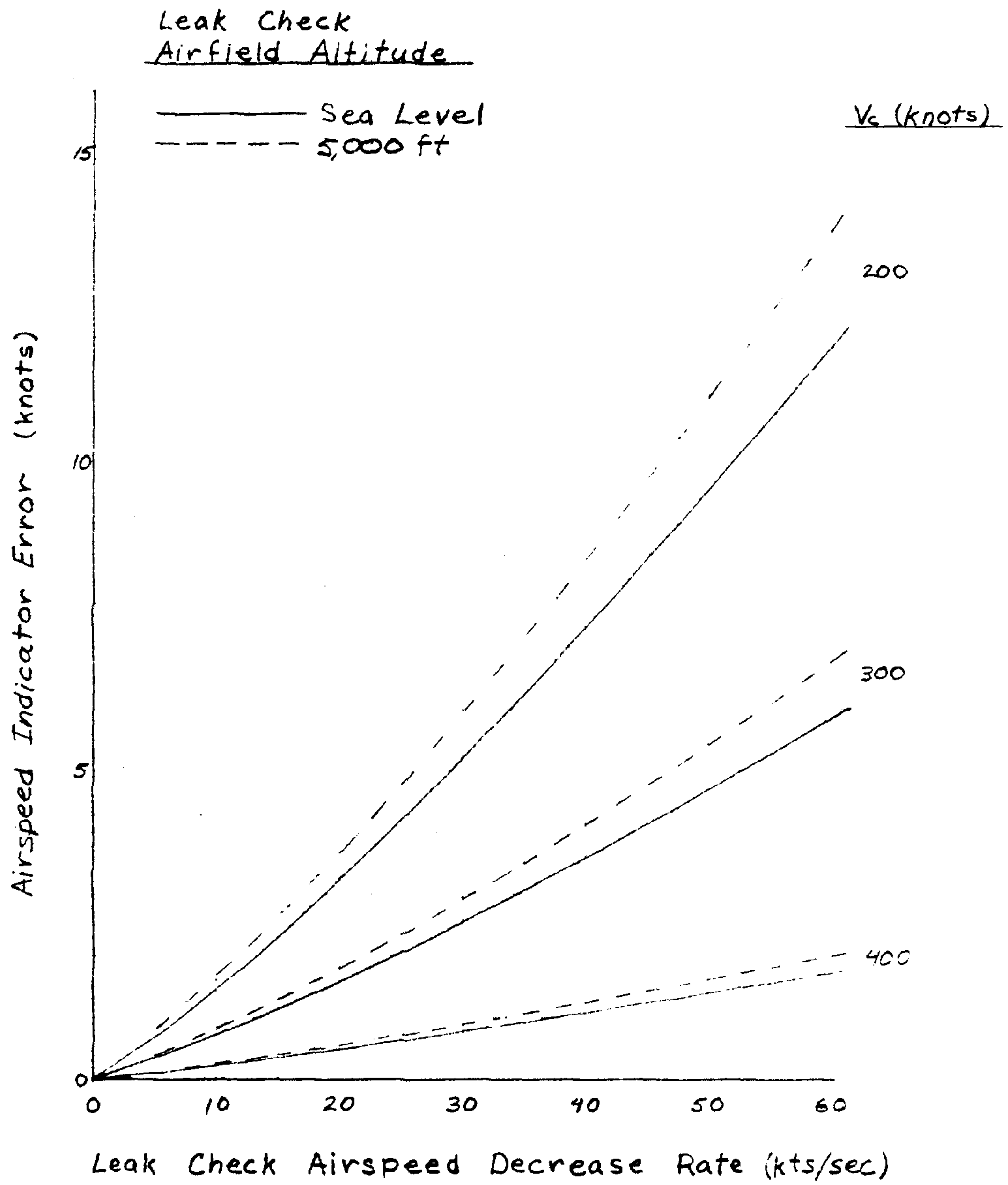


FIGURE C13 PITOT LEAK AIRSPEED ERRORS WITH ΔP_c = 14 in. Hg

Note: Apply to KC-135A
Perform leak check at 300 knots

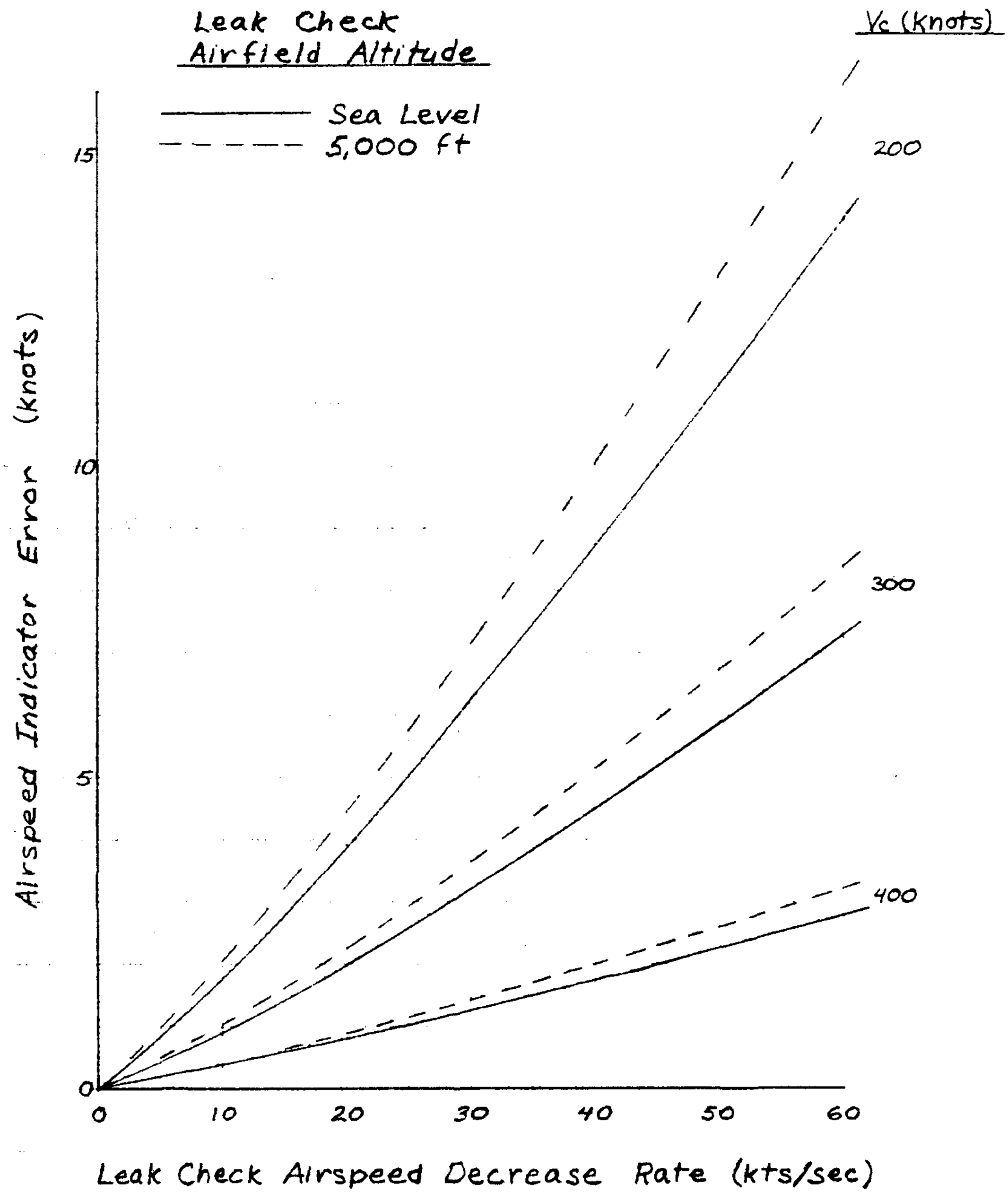


FIGURE C14 PITOT LEAK AIRSPEED ERRORS WITH $\Delta P_c = 16$ in. Hg

Note: Apply to KC-135A
Perform leak check at 300 knots

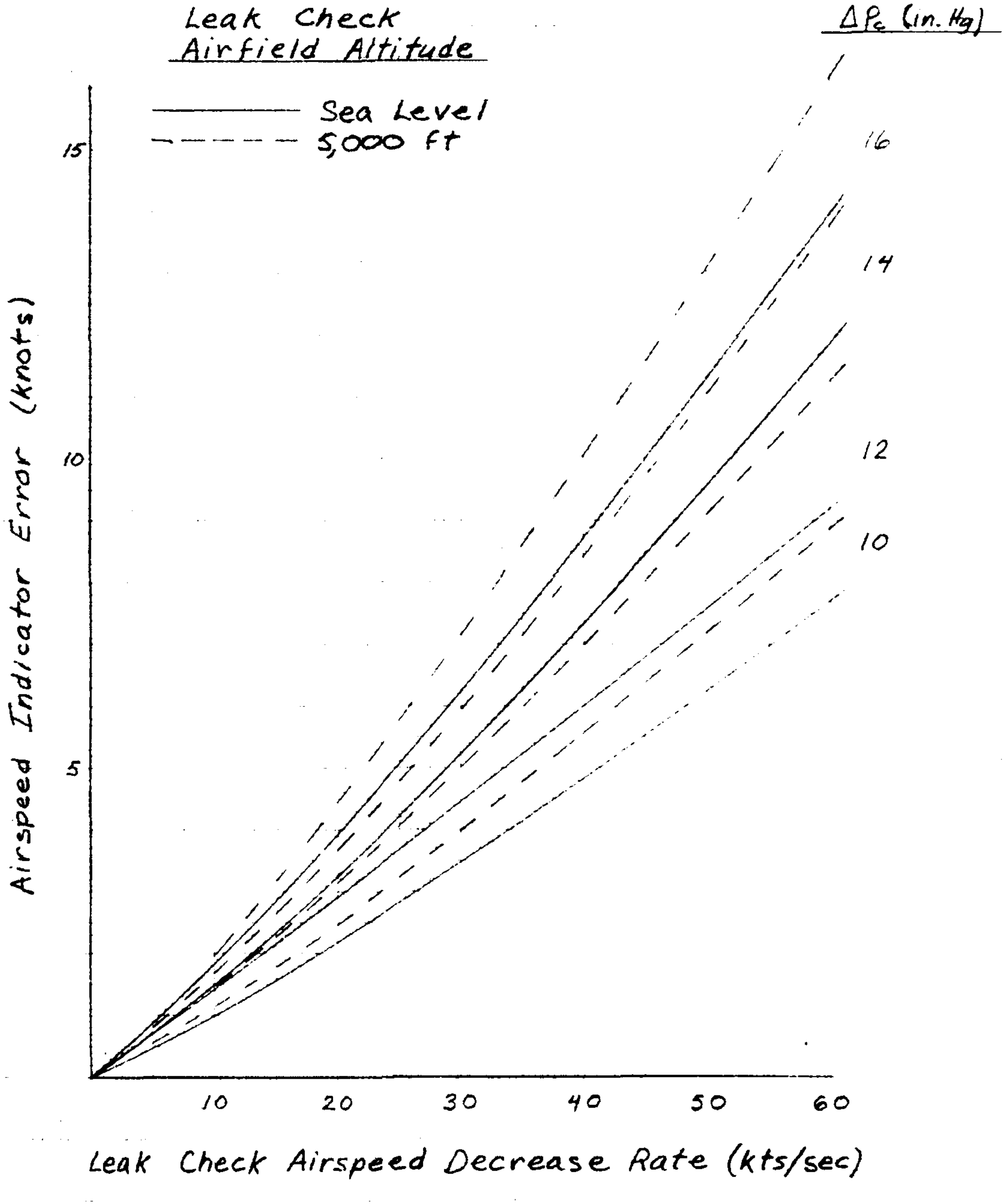


FIGURE C15 AIRSPEED ERROR DUE TO PITOT LEAK
FOR CRUISE AT 200 KNOTS

Note: Apply to KC-135A
Perform leak check at 300 knots.

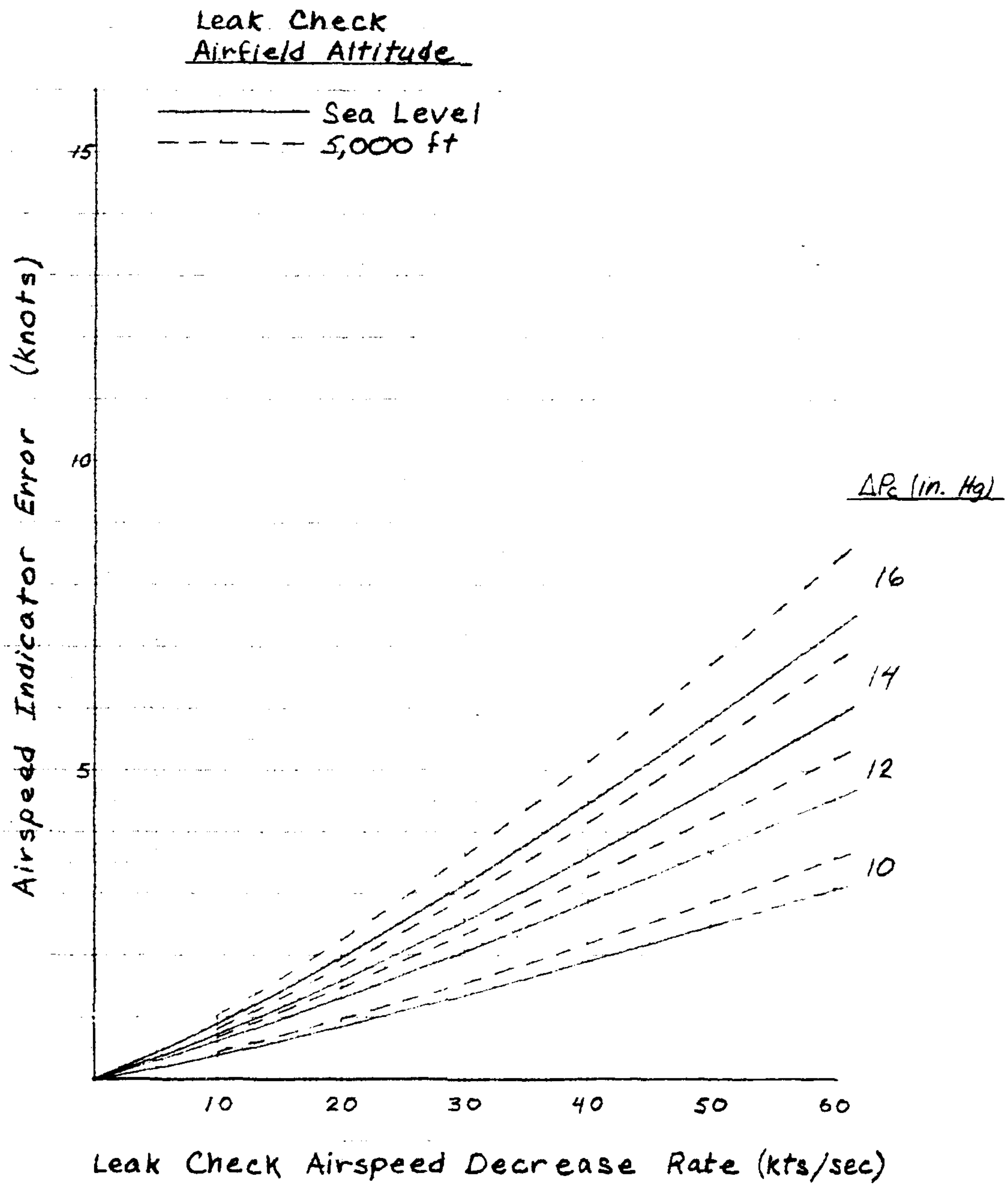


FIGURE C16 AIRSPEED ERROR DUE TO PITOT LEAK FOR CRUISE AT 300 KNOTS

Note: Apply to KC-135A
Perform leak check at 300 knots.

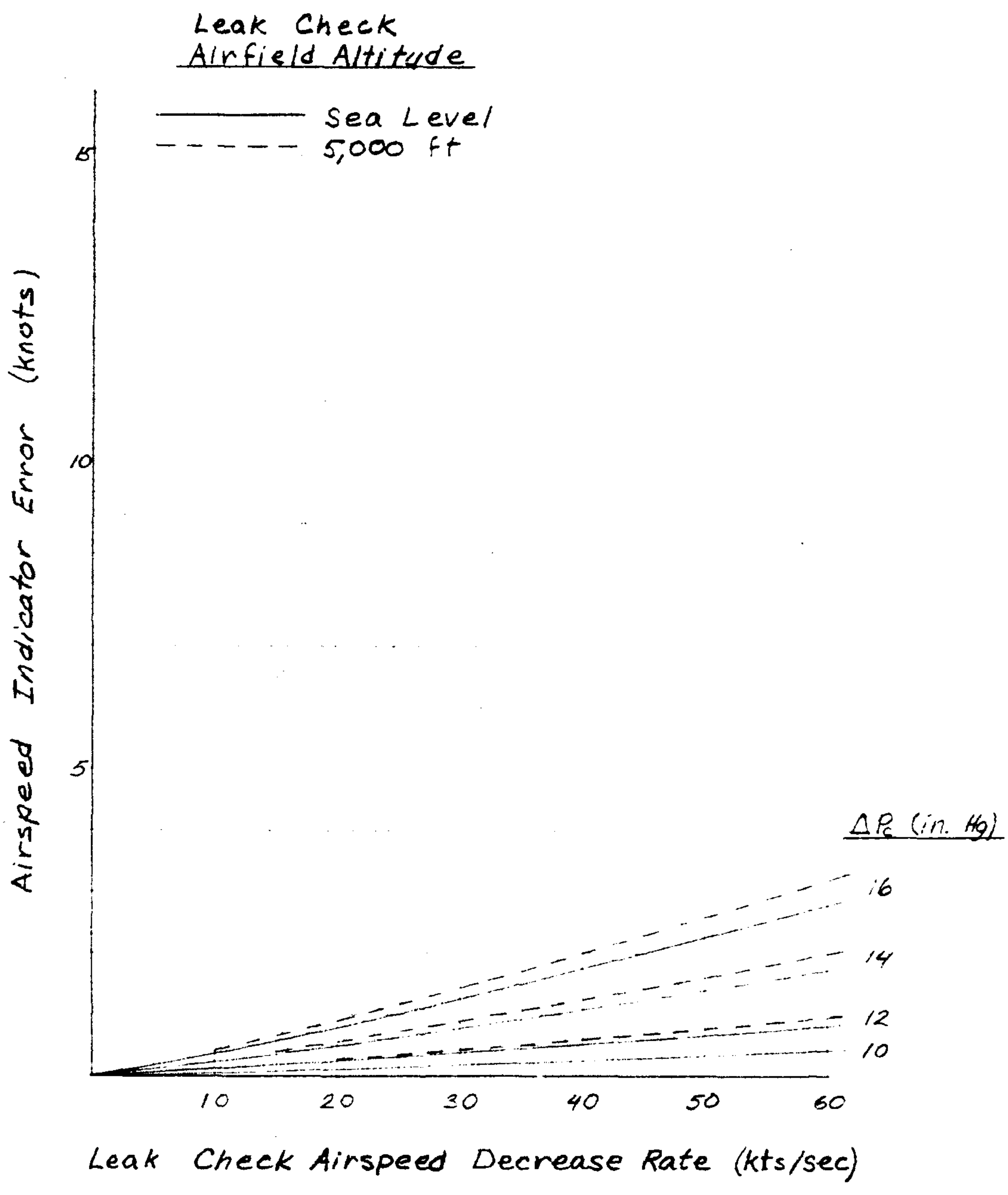


FIGURE C17 AIRSPEED ERROR DUE TO PITOT LEAK FOR CRUISE AT 400 KNOTS

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Definition	Units
AIMS	Air traffic control radar beacon system, Identification friend or foe, Mark XII Identification system, System	- - -
H_c	pressure altitude (geopotential altitude)	ft
ΔH	leak-induced altimeter error	ft
$\dot{m}$	mass flow rate	lb_m/min
No.	number	- - -
P_a	atmospheric or ambient pressure	in. Hg
ΔP_c	$P_{cabin} - P_a$, cabin differential pressure	in. Hg
ΔP_e	$P_{ic\ leak} - P_{ic\ no\ leak}$, leak-induced static pressure error	in. Hg
ΔP_e	$q_{cic\ leak} - q_{cic\ no\ leak}$, $P_{t\ leak} - P_{t\ no\ leak}$, leak-induced total pressure error	in. Hg
P_{ic}	instrument corrected system pressure	in. Hg
P_s	static pressure (at a point in a system)	in. Hg
P_t	total pressure	in. Hg
ΔP_T	$P_{cabin} - P_{tic\ no\ leak}$, $\Delta P_c - q_{cic\ no\ leak}$, pressure drop across leak hole in total system	in. Hg
ΔP_v	pressure drop through valve	in. Hg
q_c	$P_t - P_a$, impact pressure, differential pressure related to calibrated airspeed	in. Hg
q_{cic}	$P_t - P_s$, indicated impact pressure corrected for instrument error and related to V_{ic}	in. Hg
R/D	rate of descent	ft/min
ΔV	leak-induced airspeed error	knots
V_c	calibrated airspeed	knots
V. S.	valve setting, related to angular position	- - -